Final Report

Polish Space Agency

Understanding of Space Safety for the needs of future projects and activities of the National Space Program

December 2020

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Acronyms

Acronym	Elaboration
ADR	Active Debris Removal
ADRIOS	Active Debris Removal and In-Orbit Servicing
AGI	Analytical Graphics, Inc.)
APSCO	Asia-Pacific Space Cooperation Organization
ASC	Astronomical Scientific Centre
ASPOS OKP	Automated Warning System on Hazardous Situations in Outer Space
ATM	Ait Traffic Management
CAPEX	Capital Expenditure
CIE	Commandement Interarmées de l'Espace
CITA	Communication and Information Technology Authority
CMOS	Centre Militaire d'Observations par Stellites
CNES	Centre national d'études spatiales
CNSA	China National Space Administration
CSSA	Commercial Space Situational Awareness
DLR	German Space Agency
EC	European Commission
EDF	European Defence Fund
EGNSS	European Global Navigation Satellite Systems
ESA	European Space Agency
ESAC	European Space Astronomy Centre
ESO	European Southern Observatory (ESO)
ESOC	European Space Operations Centre
ESRIN	ESA Centre for Earth Observation
ESTEC	European Space Research and Technology Centre
EU	European Union
EUMETSAT	European Organisation for the Exploitation of Meteorological Satellites
EUR	Euro
EUSST	European Union Space Surveillance and Tracking
EW	Energy Weapon
FAA	Federal Aviation Authority
FCC	Federal Communications Commission
GDP	Gross Domestic Product
GEO	geosynchronous equatorial orbit
GEODSS	Ground-based Electro-Optical Deep Space Surveillance
GOVSATCOM	Government Satellite Communication
GPS	Global Positioning System
HEO	Highly Elliptical Orbit
IAA	International Academy of Astronautics
IAC	International Astronautical Congress
IOS	In Orbit Servicing
ISRO	International Scientific Optical Network
ISS	International Space Station
JMS	CSpOC Mission System
LEO	Low Earth Orbit
LEOP	Launch and Early Orbit Phase

LIDAR	Light Detection And Ranging
LPAR	large Phased-Array Radar
MC	Mega Constellation
MEO	Medium Earth Orbit
NASA	National Aeronautics and Space Administration
NATO	North Atlantic Treaty Organisation
NEO	Near-Earth Object
NEOCC	NEO Coordination Centre
OGS	Optical Ground Station
ONDE	The Office of National Digital Economy and Society Commission
OPEX	Operating Expenditure
RF	Radio Frequency
ROSCOSMOS	Russian Space Agency
SBSS	Space-Based Surveillance System
SDA	Space Data Association
SOA	Service-Oriented Architecture
SPD	Space Policy Directive
SRU	Space Resource Utilisation
SSA	Space Situational Awareness
SSCC	SSA Space Weather Coordination Centre
SSF	Strategic Support Force
SSN	Space Surveillance Network
SSS	Space Surveillance System
SST	Space Surveillance and Tracking
STM	Space Traffic Management
STPI	Sciences and Technology Policy Institute
SUPARCO	Space and Upper Atmosphere Research Commission
SWE	Space Weather
TRL	Technology Readiness Level
UK	United Kingdom
UKSA	United Kingdom Space Agency
UN	United Nations
US	United States
USA	United States of America
USD	United States Dollar
USSTRATCOM	United States Strategic Command
VAS	Value-Added Services
VAS/VAP	Value Added Services/Value Added Products
VKS	Russian Aerospace Forces
WBS	Work Breakdown Structure

1 Context and objectives of the study

1.1 Context

The space sector is a major enabler for science, technology advancements and industrial competitiveness, and a key asset towards the development of a knowledge-based society. Indeed, space activities effectively enable and benefit a large number of other sectors in the economy in both direct and indirect ways, and a number of terrestrial services, non-space industries and markets directly depend on the existence and operations of space assets. European space infrastructures and their associated services, such as those related to the Galileo and Copernicus programmes, are key assets that should be preserved from any threat that might arise within the space environment.

As a matter of fact, the space sector is experiencing a highly transformational age, ripe with growth, new ideas, new players and disruption at several levels. The number of spacecrafts launched and of associated space operations is rapidly increasing, especially in LEO where the deployment of constellation projects is expected to significantly increase (and it is already, to a certain significant extent, increasing) the number of space objects in this orbits, with some experts estimating a total number of more than 50000 satellites if all constellation projects are successfully brought forward . Such expansion of space traffic is driven by the development of small satellites (a generally accepted denomination that includes nanosatellites and microsatellites) that is perceived as a real market opportunity. Demand for small satellites is growing, for both single missions and constellations, with miniaturisation of payloads and electronics allowing missions that were previously only possible with larger systems. These satellite mass classes have found their audience across all major service verticals, such as Earth Observation, and Satellite Communication, and are allowing the entrances of new players into the space sector, both on an institutional (emerging space nations) and private (start-ups and new players) level, leading to the rise of new global challenges around the sustainability of the space environment.

As of today, regulation ensuring sound space activities and aiming at reducing the creation of space debris is often limited by national boundaries. Such legal gap that makes it difficult to require all space actors to strictly follow debris mitigation measures, and to collect proof that satellite owners and operators have intentionally tried to circumvent these measures.

Major spacefaring countries have recognized the need to intervene to reduce the threat of debris to their space activities and interests, and are currently acting under different forums to:

- **Mitigate the creation of new debris in future missions**. The mitigation consists mainly in the definition and application of design and operational guidelines to missions under development. The United Nations has recognized the issue related to the debris and acted at international level to endorse non-legally binding guidelines for the mitigation of space debris within the space law framework. As an example, the 3SOS initiative was recently launched and led by the EEAS in 2019, calling for ethical conduct in space to avoid collision and orbital debris proliferation[1].
- **Reduce the risk of in-orbit collisions generated by both active objects and orbital debris to current space missions.** The reduction of the in-orbit collision risk mainly relates to the surveillance and tracking (SST) of orbital debris with the objectives to prevent debris collisions with operating satellites and launchers, and to provide information about the trajectories of debris re-entering the Earth's atmosphere in an uncontrolled mode to prevent damage to aircraft in flight and on the ground.

1 https://eeas.europa.eu/headquarters/headquarters-homepage/67538/sos-sos-sos-eu-calls-ethical-conduct-space-avoid-collision-and-orbital-debris_en

Actively remove orbital debris. The active removal of orbital debris depends upon the definition of innovative technologies to approach, capture and remove existing debris which are currently under development. This is currently the most controversial and debated solution around the issue of space debris, as it may imply concerns related to ownership, jurisdiction, liability risk exposures or even national security.

In such context, the Polish Space Agency aims at understanding the different multi-level dynamics and characteristics in the field of space security for the needs of, among others, the National Space Programme. The Polish Space Agency wishes to collect information regarding the different aspects of the space safety market in order to identify potential opportunities in the field of space safety and sustainability.

1.2 Objectives of the study

In compliance with the Terms and Reference issued by POLSA, the study's main purpose is to provide the Polish Space Agency with an analysis of space safety needs of future projects in support of the Polish National Space Program.

PwC has identified three main objectives to be reached during this study:

1. **Provide a State of Play analysis of the space market and its legal and regulatory environment:** To reach this objective, PwC undertakes the analysis of the space market in global, European and national perspective, and conducts the analysis of the legal regulations in the global, European, and national perspective.
2. **Identify and assess opportunities for the Polish space sector in the area of Space Safety:** This objective is planned to be achieved by providing the Polish Space Agency with the ddefinition and proposal of priorities and milestones for the Polish space sector, which can be used, among others, in the design of the National Space Program. In addition, the study team will list and propose a set of activities allowing the development of the Polish space sector in the areas of Space Safety and Sustainability, in particular: proposal of legal regulations, required infrastructure, initiatives and programs allowing the development of domestic companies, R&D units and increased cooperation with foreign entities are made.
3. **Define and assess relevant concepts demonstrating Poland's potential in the area of Space Safety:** The study team will identify and suggest a concept for the development of the sector in the areas of the future such as exploration and the potential commercialization of orbital and lunar activities in the long term. This suggestion will also entail a description of the concept together with a list of good practices for the Polish space sector.

1.3 Scope of the report

This document is the draft final report of the study. It aims at providing the Polish Space Agency with an overview of the major trends characterising the space sector and driving the needs for space security activities, indicate a potential concepts for space exploration and space resource utilisation along with key elements to consider when initiating such activity, identify priorities and opportunities in the field of Space Sustainability which could be achieved by Poland, and provide recommendations on the actions required to achieve these priorities and opportunities.

This document answers to all the requirements defined in the contract between the Polish Space Agency and PwC, which are formulated as the following:

1) Analysis of the space market in global, European and national perspective.
2) Analysis of legal regulations in the global, European, and national perspective.
3) Proposal of priorities and milestones for the Polish space sector, which can be used, among others, in the design of the National Space Program.
4) Proposal of activities allowing the development of the Polish space sector in the area of Space Safety and Space Situational Awareness, in particular: proposal of legal regulations, required infrastructure, initiatives and programs allowing the development of domestic companies, R&D units and increased cooperation with foreign entities.

5) Development of a concept for the development of the sector in the areas of the future (i.e. exploration, broadly understood commercialization of orbital and lunar activities), in the long term.
6) Description of the concept, together with a list of good practices for the Polish space sector

2State of Play analysis

This state of play analysis aims at providing the Polish Space Agency with an overview and global understanding of the key dynamics characterising the space sector and its different domains and activities. Each space domain and activity are examined under a dedicated section. Even though the structure of analyses for each domain may differ from a domain to another, due to the nature and characteristics of the domain under scrutiny, the state of play analysis provides an overview of the different trends and dynamics at global, European and Polish level.

The state of play analysis starts by providing an overview of the Polish governance scheme framing national space activities and initiatives. Following the analysis of the Polish global governance scheme in the field of space activities, the state of play analysis examines the market and legal/regulatory dimensions of the following space domains and activities:

- The satellite manufacturing market
- Earth Observation
- Satellite Communication
- Satellite Navigation
- Space Exploration
- Space Situational Awareness and Space Safety

2.1 Governance of Space Activities in Poland

In Poland there are four major Ministries that overlook and govern space activities, their roles are as follows:

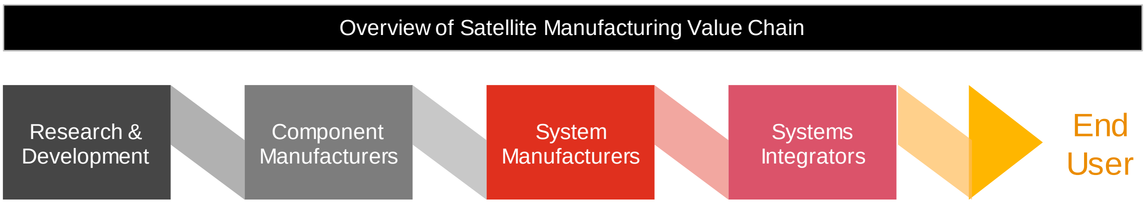
- **MRPiT**: leads space policy implementation activity and represents Poland in forums dedicated towards EU Space Policy. The MRPiT also represents Poland at ESA.
- **MNiSW:** The ministry the scientific research activities both locally and internationally. It is responsible for scientific research conducted by the National Centre for Research and Development (NCBR) and the National Science Centre (NCN). On an international front the ministry is responsible for endeavours such as Horizon 2020, Copernicus, and ESO programmes.
- **MON:** The ministry is responsible for activities related conducted in space with military and defence connotations locally, such as utilisation of space and satellite technology for national security purposes. The ministry also takes interest in activities such as Space Surveillance and Tracking (SST)/Space Situational Awareness (SST/SSA)and GOVSATCOM programmes.
- **MI:** The ministry overlooks and leads the Galileo satellite navigation programme.

1	Ministry of Economic Development, Labour and Technology (MPRiT)	2	Ministry of Science and Higher Education (MNiSW)
3	Ministry of Defence (MON)	4	Ministry of Infrastructure (MI)

2.2 The satellite manufacturing market

The satellite manufacturing value-chain is composed of four elements as depicted in the figure below, beginning with activities related to research and development, followed by component manufactures, system manufacturing, system integrators, and concluding at the end users.

Figure 1: Overview of the satellite manufacturing value chain



The first element of this value chain is related to conducting R&D activities in terms developing novel technologies that assist in enhancing payloads, systems and sub-systems of a satellite. Example of these include the development of electrical propulsion systems, optical communication systems, quantum communication, Ultra-High Throughput satellites etc. From a Polish manufacturing industry perspective, SatRevolution S.A. has been working on the development and production of Poland's first commercial satellite named Swiatowid. The company is dedicated to the manufacturing of satellite platforms and components for small satellites (both nano and micro satellites). Through the development of R&D initiatives, SatRevolution participates to cross-domain and intra-European cooperation with academia with Universities such as Université de Grnoble Alpes, AGH University of Science and Technology, and EIT+ Wroclaw. KP Labs Sp. Provides innovative flight software and has participated to several small satellite projects aiming at supporting educational and research purposes. As an example, KP Labs participated to a microsatellite mission of Intuition-1, which entails the first processing capacity allowing the segmentation of hyperspectral images in-orbit. In addition, KP Labs has also participated to an educational project, PW-Sat2 Satellite, led by the Warsaw University of Technology focused on the development and testing of an innovative deorbiting technology.

Additionally, another facet of R&D activities includes the development of technologies that assist in the production of satellites itself. Traditionally this was limited to developing procedures and standards that assisted in enhancing the satellite turn-around time. However, more recently organisations based in the such as Starlink, OneWeb/Airbus, Planet etc. have tapped into technologies that assist in mass-producing satellite components and systems.

The second element within the satellite manufacturing value chain is of developing components that are fitted into systems or sub-systems such as, power supply, propulsion, on-board computers, Altitude and Orbit Control System (AOCS) etc. Organisations such as Sonaca Group, RUAG Space, Honeywell Aerospace Inc, Anaren Inc, Arthur Behrens GmbH & Co, Space Composite Structures etc. are examples of companies and organisations that are Original Equipment Manufacturers (OEMs) within the satellite manufacturing value chain. Often these organisations are contracted by system/sub-system developers or system integrators for their mechanical, electrical or electronic components. When this segment of the value chain is viewed from a Polish perspective, it is seen that there are several organisations that fall under this category, Vigo System S.A, Creotech Instrument, SATREVOLUTION S.A., are examples of organisations that develop electronics for satellite systems, at the same time organisations such as Astromica, SENER etc are examples or organisations developing mechanical equipment for satellites. In addition to these organisations, Poland's Śląskie Centrum Naukowo – Technologiczne Przemysłu Lotniczego Sp. z o.o (SCNTPL) partnered with Thales Alenia Space in 2018 to provide the later with structural panels for its Spacebus NEO platform.

The third element within the satellite manufacturing value chain is of developing Commercial Off the Shelf (COTS) systems or sub-systems. Traditional organisations such as OHB SE, Boeing, Airbus D&S etc. are examples of systems developers for large satellites that facilitate all major space applications such as Earth Observation (EO), Satcom, Navigation, and space exploration applications. However, this segment of the value chain has witnessed tremendous growth in terms of sheer number of companies/ former start-ups that established themselves to sever the small satellite market niche, since the advent of exploiting small satellites for commercial purposes. Examples of these companies are GomSpace, Aurora Propulsion technologies, Clyde Space (now AAC Microtec), Berlin Space Technologies, Crystalspace etc. Having said that it is also important to note that, small satellite operators are usually seen to be vertically integrated and to a certain extent manufacture a vast majority of their sub-systems in-house, an example of this is Planet, ICEYE, Skybox Imaging (now Planet).

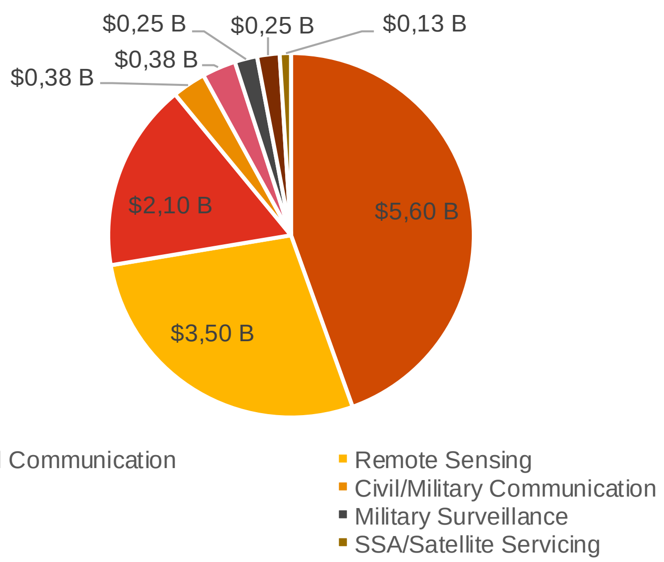
Polish companies are also establishing themselves within this segment of the value chain, and dedicating their efforts towards developing systems for small satellites, a notable example of this is SATREVOLUTION an organisation that is specialised in manufacturing satellite platforms, optics and optoelectronics

The fourth element of the manufacturing value chain is related to organisations that are involved in assembly, integration, and testing of satellite. These organisations are usually primes such as Thales Alenia Space, Airbus D&S, Maxar Technologies, OHB SE etc. However, certain small satellite manufacturers and operators such as GomSpace, ClydeSpace (AAC Microtech), LeoStella etc. fall in this category too. However, when viewing this segment of the value chain from a Polish perspective it is seen that traditional primes have established themselves in Poland by partnering with local companies with the aim of integrating satellites in the future. An example of this is PZL “WARSZAWA-OKECIE” S.A, an airbus company that has developed a 500m^2 clean room facility for future integration of satellites. On the other hand, there are some organisations of such as Creotech Instruments, ITTI etc. that are dedicating their efforts towards integrating and testing small satellites.

The last element of the satellite manufacturing value chain is that of the users, these users are predominantly satellite operators, procuring satellites for commercial, defence, scientific, educational and exploration purposes. Organisations such as Warsaw University of Technology, Polish Academy of Science (Space Research Centre), ICEYE serve as example of satellite operators based in Poland.

Furthermore, the market size of global satellite manufacturing value-chain was estimated at USD 12.5B in 2019[2], with the following market segmentations,

Figure 2: Satellite manufacturing market share by space applications



2.2.1 Market Dynamics

The satellite manufacturing market is driven by the emergence and development of small satellite systems and the growth of space systems based on a constellation of small satellites. Such market uptake towards the adoption of small satellite systems is mainly explained by a growing need for high-speed and near-real time data access. These trends are further characterised in the following paragraphs.

Development in miniaturisation technologies

Satellite miniaturization technologies have been under constant development and improvement to increase the capacities of small satellites, and to enable a service quality similar to that of conventional satellites with much lower costs. This has been emphasized with the number of small satellite start-ups working on the development of new innovative technologies and methods

[2] SIA State of the Satellite Industry Report, June 2020, available at: https://brycetech.com/reports

for these satellites, and the number of nano or micro satellites being developed in universities, high schools and institutions. Furthermore, the entire set of satellite subsystems and components encompassed with small satellite (power supply, propulsion, microchips, payload equipment, etc.) is under constant development to achieve efficiency with the cost and size reductions.

The following table provides a non-exhaustive list of the main small satellite systems developers at global, European and Polish level:

Table 1: List of main small satellite system developers and manufactures (non-exhaustive)

Region	Company name	Country
Global	Dynetics	US
	L3Harris Technologies	US
	Lockheed Martin Corporation	US
	NanoAvionics	US
	Northrop Grumman Corporation	US
	Planet Labs Inc.	US
	Raytheon Technologies Corporation	US
	Sierra Nevada Corporation	US
	SpaceQuest Ltd.	US
	Spire Global	US
	Tyvak Nano-Satellite Systems	US
	Magellan Aerospace	Canada
	Axelspace Corporation	Japan
	Dauria Aerospace	Russia
Europe	RUAG Group	Switzerland
	Gomspace	Denmark
	Berlin Space Technologies GmbH.	Germany
	Innovative Solutions In Space B.V.	Holland
	GAUSS SRL	Italy
	Clyde Space Ltd.	UK
	Sky and Space Global SpaceWorks Enterprises	UK
	Surrey Satellite Technology Limited (SSTL)	UK
	Creotech Instruments S.A.	Poland
	SATREVOLUTION S.A.	Poland
	WiRan Sp. z o.o.	Poland

Increased demand for constellations

The traditional satellite market, characterised by medium to large satellite with a total mass superior to 500kg is essentially being disrupted by the small satellite model, which leverages agility over satellite design. The evidence of this can be found in satellites ordered, for instance prior to 2016 the average number of large GEO satellite (satcom) ordered would be between 15 and 20 satellites a year. However, since 2016 this hasn't been the case. For instance, in 2017 there were 7 GEO orders, followed by 5 in 2018, and 10 in 2019. The focus has shifted towards developing large satcom constellations comprised of small satellites, for instance Starlink has already manufactured and launched 893 satellites[3], and is deemed to possess the capability of manufacturing approximately 120 satellites per month[4]. Likewise, the joint venture between OneWeb and airbus has already manufactured and launched 74 satellites (including technology demonstration satellites) and plans to manufacture the remained of its constellation of up to 900 satellites through its new factory in USA (Florida). At the same time when viewing the manufacturing market from an EO lens, the conclusion is not significantly different. A vast majority of traditional satellite operators are opting to procure/manufacture several small satellite as a part of a mega constellations as opposed to launching few large satellites. An example of this is Digital Globe's (now Maxar) WorldView legion constellation.

The following table provides a classification of the different types of satellites which compose the small satellite category:

Table 2: Classification of small satellite types

Satellite mass	Category
Between 0.1 and 0.99 kg	Picosatellite
Between 1 and 10 kg	Nanosatellite
Between 10.1 and 100 kg	Microsatellite
Between 100.1 and 500 kg	Minisatellite

The need for large amounts of data more quickly and in near-real time

The downstream element of the geospatial market has witnessed an increasing dependence on EO data to answer the different and growing needs of their customers and end-user applications such as agriculture, security and transportation etc. This has led to the emergence of new trends in the geospatial market embodied in the transfer of industries from data provision to insight provision utilizing Big Data analytics tools to deliver better quality and more customized solutions for their user needs. Small satellite constellations guarantee uninterrupted access to data and are capable of monitoring any region of earth in real time due to the large number of satellites in a constellation, and their high revisit frequency. Not only does deploying small satellite constellations ensure real-time monitoring, but it also ensures the provision of large amounts of data as it supports the operation of a large amount of small satellites

In order to assess the market fundamentals at play such as barriers to entry, and competition within the satellites manufacturing industry it is essential to highlight and recall the existence of two different and distinct business models and approaches: the deployment of one single spacecraft, categorised as medium or large (>500kg), or the deployment of several small satellites composing a constellation architecture. Both these approaches and associated markets are fundamentally different and possess various levels of external dependencies, competition, and barriers to entry. For instance, on an average between 2016 and 2020 there are 41 companies being registered, cumulatively accounting for 205 companies between the periods.[5] The ability to purchase COTS systems and develop small satellites has significantly lowered market entry barriers, however making the market highly competitive. On the other hand, manufacturing large satellites still requires a significant amount of technological prowess, and as such possess a greater barrier to entry.

Lower barrier to entry has allowed new space fairing nations such as Poland to establish themselves as serious players within this market, with the aim of gaining the technical know-how by developing small satellites, and eventually translating this into manufacturing larger much more complex satellites. As an example, Poland has launched the

The following table provides the main Polish small satellite projects:

[3] Available at: https://space.skyrocket.de/doc_sdat/starlink-v1-0.htm
[4] Available at: https://www.assemblymag.com/articles/95838-spacex-is-manufacturing-100-plus-internet-satellites-per-month
[5] Available at: https://www.nanosats.eu/

Table 3: Polish small satellite missions

Spacecraft ID	Operator	Mass and category	Mission	Launch date
KRAKSAT	AGH University of Science and Technology (Akademica Gorniczo-Hutnicsa)	1kg – Nano satellite	Education and technology demonstration	2 019
ŚWIATOWID	SatRevolution and AGH	2kg – Nano satellite	Earth Observation	2 019
PW-SAT 2	Warsaw Polytechnic (Warsaw University of Technology)	3kg – Nano satellite	Technology demonstration (deorbiting system)	2 018
BRITE-PL 2 (HEWELIUSZ)	Polish Space Research Centre (CBK)	7kg – Nano satellite	Photometric observations of bright stars	2 014

2.2.2 Regulatory Environment

The satellite manufacturing market regulations can be split in two distinct components. Just like any other industry, satellite manufacturing responds to regulations that apply to manufacturing processes. But satellite manufacturing must also respond to sector-specific regulations that include industry standards that partly shape manufacturing processes.

Industrial regulations will be highly dependent on existing international standards but will particularly be conditioned by the European Regulations that are in place with regards to environmental protection, like the directive on industrial emissions6 or the protection against industrial hazards (etc.). Examples of such regulations include the SEVESO directive[7]. The SEVESO directive is a directive that fights for technological disaster risk reduction and that will regulate manufacturing sites potentially hazardous including when the storing of sensitive material is involved which satellite manufacturing and launcher manufacturing materials can be typically involved. The SEVESO directive applies to 12.000 industrial establishments in the EU where dangerous substances including chemicals and petrochemicals as well as fuels are stored. The SEVESO directive dates back from 1982 and is since regularly updated as we are currently at the third iteration of the directive (SEVESO-3 since 2012).

Due to their positioning in the EU's legal order, directives apply to all industrials active in Member State countries and are integrated in the national legal order either directly or through an express transposition by national policymakers. As an example, satellite and rocket manufacturing sites in France are typically considered Seveso sites.

Standardization efforts in satellite manufacturing

In order to ensure proper standards definition and certifications, standardization bodies have emerged at both European and International level in order to ensure "space-certified" quality controls.

The European Cooperation for Space Standardization (ECSS) is developing standards for space-related activities that members of the European Space Community should comply with. It is the strongest, yet not the only actor when it comes to standardization efforts in the space sector. The ECSS is not an established organization, and as such, is not a legal entity. It is rather an association of legal entities establishing standards which copyright is owned by the European Space Agency (ESA). It is composed of six space agencies; ASI (Italian Space Agency), CNES (French Space

[6] Directive 2010/75/EU of the European Parliament and of the Council of 24 November 2010 on industrial emissions (integrated pollution prevention and control)
7 Directive 2012/18/EU of the European Parliament and of the Council of 4 July 2012 on the control of major-accident hazards involving dangerous substances, amending and subsequently repealing Council Directive 96/82/EC

Agency), DLR (German Space Agency), The Netherlands Space Office, Norsk Romsenter (Norwegian Space Agency), UK Space Agency, and Canadian Space Agency as an associate entity to ESA, together with ESA itself and Eurospace, representing the industry. In addition, some organizations have an observer role in ECSS e.g. Comité Européen de Normalisation Électronique et Électrotechnique (CEN-CENELEC), European Defence Agency (EDA) and European Organisation for the Exploitation of Meteorological Satellites (EUMETSAT). Standards developed by the ECSS are here to help harmonize processes in the space community, including manufacturing, in order to reduce costs and improve reliability.

Other standardization bodies exist and are relevant for the space sector. They complement the works of ECSS either by providing additional standards specifically for the space sector, or by providing field-specific standards that also apply to space. Such bodies include :

- The Consultative Committee for Space Data Systems (CCSDS) is an international organization, composed of space agencies and industrial partners that aims at developing standards in data management in support of space science
- The Institute of Electrical and Electronics Engineers (IEEE) focuses on engineering, computing and technology information, which are critical components in space science missions
- The European Space Components Information Exchange System (ESCIES), as part of the European Space Components Coordination (ESCC), serves the purpose of being a repertoire for electronic and electro-mechanical parts. It is hosted by ESA.
- The European Preferred Parts List (EPPL) is another repertoire intended for European manufacturers, listing the best components to be used for spacecraft hardware and associated equipment manufacturing.

The International Organisation for Standardization (ISO) also cooperates with other Standard Development Organisations for the development of standards related to space activities. ISO disposes of a Technical Committee, the TC20, dedicated to develop standards related to the space sector. The TC20 is composed of two subcommittees: the SC13 which focuses on Space Data and Information Transfer (downstream); and the SC14 which deals with standards for Space Systems and Operations (upstream). The SC14 was formed in the early 90s with the main purpose to harmonise and develop standards forming an agreement between all space agencies and companies involved. Five initial Working Groups were created, and then two more were added:

- WG1: Design engineering and production
- WG2: Interfaces, integration and test
- WG3: Operations and ground support
- WG4: Space environmental (natural and artificial)
- WG5: Space System Program Management and Quality
- WG6: Material and processes
- WG7: Orbital Debris

The processes that are followed when developing a new ISO TC20/SC14 standard are the following:

- SC14 member country submits a new work item proposal, containing the scope of document, its rationale, the project lead (PL), the timeline, market needs, etc.;
- This work item proposal is then circulated within SC14, and SC14 members vote and nominate experts on the proposed work item;
- If approved, a WG is assigned (or a new one is formed) to develop the working draft (WD);
- The WG is then developed by the PL and the nominated experts and they decide when it becomes a Committee Draft when it becomes mature enough;
- When this Committee Draft is approved, it becomes a Draft International Standard, which can be reviewed by all ISO member countries;
- When all comments and concerns on the Draft International Standard are resolved, then the document becomes an Official Standard.

Poland does not appear to be a member of the ECSS initiative. Should Poland, through the POLSA, become an active member, its contribution would benefit to industrials active in the satellite manufacturing value chains and increase the outreach of POLSA as a major partner in space industrial initiatives.

2.2.3 Perspectives

Based on the market projections it can be assumed that thousands of satellites are expected to be manufactured in the coming decade alone. If projects go as per plan, Starlink alone shall manufacture and launch 12000 to 42000 spacecrafts in the coming decade. The point of concern here is the fact that the failure rate of Starlink satellites is about 2.5%, this means at this failure rate if Statrlink was to manufacture and launch a small constellation (i,e 12000 satellites as opposed to 42000) there would be 300 uncontrolled satellites in LEO[8]. Even at 1% failure rate the coming years, the impact would be significant in terms of space safety. Moreover, as almost the entire satellite along with its systems, sub-systems, and component are mass produced, one faulty batch of components could significantly increase the failure rate and render a vast majority of LEO orbits unusable. As such it is eminent to update and develop new standards as well as regulations and procedures on an international level to address this issue, and ensure that access to space and commercially exploitable orbits remain operable for all nations.

The perspectives in terms of future regulations when in comes to the satellite manufacturing market are definitely oriented towards the increase in standardization efforts and standardized components. This trend is supported by the growth in number of countries who are wishing to develop satellite manufacturing capabilities in the world, through the construction and installation of satellite manufacturing, assembly, testing and integration facilities (so called M-AIT facilities). These will require increased standardized procedures to be fully efficient and operable with a maximum number of satellites. In addition, it can be expected that regulations in terms of export-control will be of growing importance as space superpowers like China and the US will continue trade wars, and those trade wars will have repercussions on other space superpowers like the EU, India or Japan. Those countries might decide in the sort future to create their own ITAR-equivalent in order to counter-attack on export control regulations that penalize their industries. Because such regulations must be EU issued, Poland should not expect to have an independent regulatory position on the topic but will rather be dependent on EU-level decisions.

2.3 Earth Obseravtion

This section of the state of play assess the Earth Observation (EO) market and its value-chain, and makes an effort towards mapping the global, European, and Polish players active within this EO ecosystem. In addition, the assessment highlights the market dynamics at play, and addresses the core technological and business-related trends within the EO value-chain. Lastly, the assessment herein identifies the challenges that this growing market places on space sustainability/safety, and consequently makes some high level comments towards the impact it could have on the upcoming Polish EO companies.

2.3.1 Overview of the value chain

The satellite based EO market is composed of four elements that depict its value-chain, this is illustrated in the figure below.

[8] PwC analysis

Figure 3: Overview of the Earth Observation (EO) value chain

The first step towards the exploitation of EO data is acquiring it from the source (i.e. acquired from Optical or SAR sensors). With growing awareness on the importance of EO data in meeting the daily needs and requirements of the different industrial sectors and downstream markets, more satellites are being launched. Thus, the volume of data being produced has grown experienced a significant growth for the last ten years, with highly variable and diverse data being generated at a high rate: forming "Big Data. Organisation such as Planet, Maxar Technologies, 21AT are example of companies that utilise their own satellites to acquire raw satellite data. Likewise, in Poland ICEYE is a start-up that has been acquiring raw SAR satellite data.

The second segment within the EO value chain comprises activities which aim to enhance the raw data acquired from satellites and transforming it into Value-Added-Products or Value-Added-Service. This is done by applying a layer of processing to the data files sought from the satellite, for instance applying geometric corrections and applying shape files etc. A vast majority of the organisations that acquire data (Planet, Maxar, Airbus Intelligence, ICEYE), add this additional layer of processing as a natural progression to their commercial client requirements. Polish companies developing solutions in the field of Value Added Services creation comprise Wasat Sp., Blue Dot Solutions, and Cloud Ferro (non-exhaustive list).

The third segment within the EO value chain is of converting VAS/VAP's into information productions, this is done by adding additional layers of information such as traffic information, street names, or other such external data files to develop a product that provides imagery that is embedded with information relevant to the end-user. Organisations such as Exolabs, Planetek italia, radiant solutions (owned by Maxar), GAFAG, etc. develop such products, in a vast majority of the cases the players that provide information products do not necessarily own or operate satellites. Companies such as ICEYE, Astri Polska, and ProGeo 4D are examples of organisations that develop information products.

The fourth segment within the EO value chain is that of Big Data analytics, this is a fairly new domain. The revolution of cloud computing has significantly reduced the cost of storage and computing power for many customers. Cloud computing, combined with a push for digitalization, has opened the door for many new solutions and approaches to handling data. Big data – the concept of a large volume of structured and unstructured data that is produced at a high rate – has particular relevance to Earth Observation, including the barriers of storing and managing such large amounts of data. Copernicus alone will deliver in excess of 10 petabytes of data every year when all Sentinel satellites are operational.[9] The European Commission launched the Copernicus Data and Information Access Services (DIAS) to support the process of accessing this data and information, so that the challenge associated with downloading and storing can be avoided by users. When DIAS is fully functional, it will act as a cloud-based one-stop shop to provide unlimited, free and complete access to Copernicus data, with scalable computing and storage environment for third parties. Supported by ESA, CreoTech Instruments and CloudFerro SP. both Polish companies, are developing the EO Innovation Platform Testbed Poland which aims at fostering the access mechanism to cloud-based resources, encompassing Infrastructure as a Service (IaaS) and Data as a Service (DaaS).

Commercial Earth observation satellite operators are continuing to pivot away from simply collecting imagery, to analysing the data for actionable intelligence, especially with artificial intelligence (AI) driven data analytics. Three techniques increasingly being offered within solutions based on or utilizing satellite imagery are:

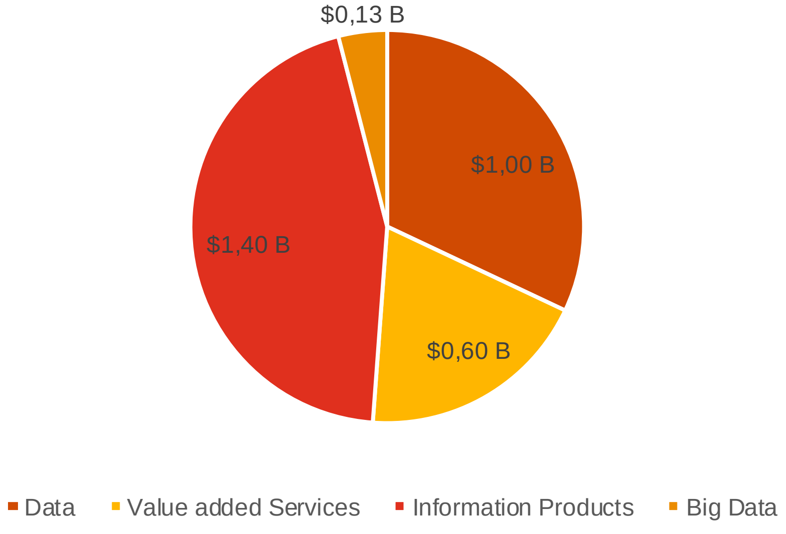
- **Machine learning**, a method that automates analytical model building based on the concept that systems can learn from data and make decisions with minimal human intervention;

[9] http://copernicus.eu/news/upcoming-copernicus-data-and-information-access-services-dias

- **Predictive analytics**, which is a branch of advanced analytics using data mining, statistics, and AI, utilized to make predictions about unknown future events;
- **Automatic change detection**, where algorithms can detect changes in the imagery of the same location, e.g. deforestation, identification of new artefacts, suspicious activities around critical infrastructure.
- **Predictive analytics** can be especially helpful when determining crisis and security risks and mitigation. Automatic change detection is used for monitoring critical infrastructure and other security challenges, as well as highlighting the damage occurred through before-and-after imagery related to natural disasters and other crises. They are also utilized in industrial decision making, such as for agriculture and transportation or for various businesses and commercial applications. Companies such as BlackSky and DigitalGlobe have even acquired analytics companies such as OpenWhere and Radiant, respectively.

The last element of the EO value chain is that of the end users, these users are predominantly satellite operators, data analytics provides, and government institutions Furthermore, the global EO market size as per NSR's EO market report 10th editions is of USD 3.15B, and its size per product type is as follows:

Figure 4: Market share distribution of EO products and services in 2017[10]



It is also critical to point out that approximately 40% of these revenues generated in 2017 were from North America, 27% attributed Europe, and the remainder 33% were attributed to the rest of the World.

2.3.2 Market Dynamics

The main trends that are witnessed within the EO market are detailed in the following paragraphs.

High demand for insights

The rapid growth and changes in the digital economy of today has pushed companies and organizations towards the search for more agile methods of operations by integrating data-based decision making in their processes. In fact recent statistics by Accenture and General Electric have indicated that the majority of the companies interviewed believe that BDA is capable of shifting their competitive landscape within the next couple of years. Over half agreed that if they do not adopt BDA they would lose their positioning within the market.[11] The capacity of BDA to optimize their work and customize their solutions has driven the demand from different

[10] NSR Market report
[11] Frost and Sullivan, 2017

businesses. It has enabled these organizations to build their own customer segments and target them with higher accuracy and precision.

IT Development

IT technology evolutions today have enabled entities to access and utilize databases they didn't have the capacity to access before. It enables them as well to combine different types of data (such as the NoSQL database) of different formats and standards. This has enlarged the scope of benefit from data, where terabytes and even petabytes of data are analysed in order to provide key messages and coherent results regarding the insights required. Cloud storage and computing have contributed to solving the problem of storage space availability and costs to utilize the different dataset

Business Model Flexibility

The migration from perpetual licensing toward subscription-based models have enabled SMEs to afford and utilize BDA within their businesses where they have the flexibility to explore use cases and develop prototypes without obliging to long term commitments

Data Privacy & Security

Enterprises and organizations had in the past been sceptical about the adoption of BDA due to data privacy and security issues, especially following several data breaches. However today, the availability of enterprise-grade security and data management due to the development of private clouds, cyber security and encryption etc. has risen the trust in BDA and thus its adoption

BigData, Data Fusion and Multi-Intelligence Fusion

The availability of large amounts of data including imagery available for free (e.g. Copernicus, Landsat), or at very low prices, and especially the data archives of more than 30 years have facilitated the access to information, and combined with advancements in AI and computing, has improved the accuracy and quality of insights. In fact the technologies enabling the fusion of different data types such as EO data with open sources information and in-situ data available on the web have produced very high value added products. Advancements in data fusion enable to merge multi-sources of unstructured, semi-structured and structured data to an extent that was not possible before, and so many entities nowadays have huge internal repository of unstructured and semi-structured data not fully exploited. The value of the merger of internal repository of data with advanced imagery (drones and satellites) is expected to unlock promising new applications for non-technical end-users.

The trends highlighted above in conjunction with the boom in small satellite EO market has significantly reduced the entry barriers within the EO market. This remains true for organizations that aim to provide raw data, value added services, and to certain extent information products. However, when it comes to developing Big Data analytics capabilities the entry barriers rise, as BDA applications require significant technological proves in terms of developing algorithms that can provide meaningful and actionable insights repetitively.

2.3.3 Regulatory Environment

National space law regarding EO satellite primarily focusses on the launch and in orbit operations of EO systems, not in the first place on the data produced by the systems. In a few countries however, this has led to the adoption of specific legislation on the licensing of private remote sensing activities. Given the growing importance of space and EO as a business-enabling segment, we can expect an increase in EO-specific regulations in the future. The following particularities of Earth observation are key drivers for adopting specific legislation:

- National security, national defense, foreign policy, international relations
- Cybersecurity
- Data protection (not only, but also including personal data protection)
- International obligations on data sharing under the UN Remote Sensing
- Principles, the Disaster Charter, GEOSS and other instruments.

With the advent of numerous new private operators, large smallsat constellations, and new technology capabilities in instruments, near real time data availability, data storage, access, and analytics, new regulatory challenges emerge. Overall, national laws and regulations show large variance in approach and implementation details.

All countries with EO legislation review their legislation and regulatory practice from time to time in order to consider technology advancements, the development in global markets, lessons learned and national security, defense and foreign policy developments. Generally, the thresholds defined concerning resolution have been lowered step-by-step, whereby the US is “setting the scene” with other countries to follow. While there is no formal coordination mechanisms, the (western) countries with EO legislation exchange and informally coordinate their approach and practice.

While outcomes cannot be easily predicted, it is rather safe to assume that SAR and video instruments, high-revisit cycles by larger constellations, high-content information based on powerful analytics, and the overall increase in countries with EO system capabilities will be major aspects during the upcoming regulation update processes.

In addition to national EO legislation, institutional EO space data policies define principles that are then further elaborated in less strategic documents (e.g. user license terms and conditions, price list etc.)

- Data policy: the EO space data policy is developed by the satellite owner/operators to set the main principles for the provision of the EO satellite generated data and products. It sets principals, it is not a piece of legislation and is not legally binding per se.
- Data User License T&C: there are developed by the satellite owner/operators and they set the T&C under which the user can utilize the EO space data/products. They are binding between the parties (i.e. the licensor and the licensee)
- Data pricing list: this is developed by the satellite owner/operator and/or its exclusive data provider and it sets the prices under which the EO space data/products are made available

Institutional EO space data policies typically set principles along 6 main topics that include:

- Data Ownership: who owns the data generated by the EO satellite, thus sets the “rules of the game”
- Data Access/availability: who can access the data (e.g. anyone, user categories), what type of data access rights a user has, if there are more access routes (e.g. institutional and commercial)
- Data Pricing: what type of price apply to data, if any (e.g. free of charge, COFUR alike, commercial)
- Data Usage: what utilization rights user have, and if there are restrictions (e.g. for scientific purpose only, project scope, non-commercial)
- Data Distribution/re-use: if the user can distribute the received data further or there are restrictions
- Data intellectual property (IP): To what extent, the owner of EO satellite primary data retains IP on processed data/products made by the users

International Law & principles and European Regulations

There are several international principles in existence, that represent the international hierarchy of principles for Earth Observation and EO space-based data policies:

UN principles

UN principles on Remote Sensing of the Earth from Outer Space (Res. 41/65, 1986), which establish principles (e.g. freedom of sensing, cooperation, duty of dissemination of data for harmful phenomena to natural environment, and right of access of Sensed State). These are voluntary and therefore are not legally binding under international law.

International Guidelines and Practices:

- Global Earth Observation system of system (GEOSS) data sharing principles of 2005 and Guidelines of 2009, which promote the full, open and minimum cost approach to EO data
- World Meteorological Organization (WMO) policy & practice for exchange of meteodata and products, including relationship in Commercial Meteorological Activities (Res. 40, 1995,60,2015)

These are voluntary and not legally binding under international law, although being politically endorsed

The European Inspire Directive of 2007

The Inspire Directive 21 of May 2007 is the main regulation for the use of space-based data in Europe: it aims to establish an infrastructure for spatial information to support European environmental policies. Concretely, this means that it aspires to facilitate the sharing of environmental spatial data among public organizations on the one hand, and the public access to this information on the other. The Inspire directive creates certain obligations for the Member-States, including the creation of a metadata catalogue, the free access to metadata, access to the data for actors with a mission comprehended in the Inspire framework, and the existence of an organisation which goal is to ensure the good execution of the Directive.

National and Institutional EO data policies

Data policies are typically set at the level of the institutions that operate Earth Observation satellites, collect the data and issues them. With respect to Institution/Agency space EO data policies (US Landsat, Copernicus, Eumetsat etc.), the institutional space EO data policies are further elaborated into principles & regulated data access, distribution or pricing. There are mandatory for all institutional programs/missions and bind institutions as well as other involved parties via procurement contracts or licenses of exploitation. Institutional space EO data policies are implemented via various instruments (e.g. terms & conditions, licenses, agreements) that are legally binding between signing parties.

Standards developed in the Earth Observation domain

As with other space domains, it is necessary, with Earth Observation, to distinguish the standards in the upstream, midstream and downstream parts of the sector. The European Association of Remote Sensing Companies (EARSC) is a non-profit European organization that coordinates and promotes activities of its members in relations to EO-based data. Following an ESA project that looked into the feasibility of a quality certification scheme specifically tailored to the Earth Observation Industry, EARSC created the Industry Best Practices Working Group, leading to the development of domain specific documentation including:

- A Scheme Description, based on the relevant ISO standards and Guidelines pertaining to certification schemes
- Management System Requirements, focusing on the needs of the Earth Observation industry with respect to management system requirements;
- Document Requirements Definition for Product Specifications

In addition to this industry best practice group, series of EO data processing and formatting initiatives were put in place over the past decades and include:

- **The Consultative Committee for Space Data Systems (CCSDS):** the CCSDS is a multi-national forum for the development of communications and data handling systems standards for spaceflight founded by the major space agencies in the world. EO missions development and data management in Europe largely follow CCSDS-developed standards.
- **The Coordination Body (DCB):** the DCB has ensured coordination among European and Canadian EO space agencies, and has produced best practices and guidelines. GSCB has also triggered the definition of Open Standards in the EO ground segment and data management domain mostly through the Open Geospatial Consortium (OGC). Subgroups within the DCB address issues like EO data preservation, discovery, access, processing and analysis, network of resources for data exploitation, common reference architectures and

interoperability at data and infrastructure level. Several standards triggered by GSCB/DCB are now used in the frame of the Copernicus programme (e.g. SAFE, HMA, OpenSearch).

- **The Open Geospatial Consortium (OGC):** the OGC is an international not for profit organization committed to making quality open standards for the global geospatial community. These standards are made through a consensus process and are freely available for anyone to use to improve sharing of the world's geospatial data. Space agencies and industry are cooperating in their definition.
- **The Committee on Earth Observation Satellites (CEOS)** is the mechanism that ensures coordination among entities operating and managing EO space missions and data since 1984. CEOS has 64 member agencies worldwide. Its dedicated sub-groups have generated several best practices and guidelines over the years which are now used as reference for CEOS members. In 2018, the European Commission chaired the CEOS.

2.3.4 Perspectives

As per NSR's EO market report 10th edition, it is estimated that the satellite based EO market will double from 3.1B in 2017 to approximately USD 6.6B by 2027. It is interesting to note that the Big Data market is to reach USD 357B by 2027, growing around 1600% from its USD 22.8B market share in 2017. This 16 fold growth will have require significant amounts of, this data may come from UAV's, HAPs and other such non-space sources. However, a vast majority of data will come from small satellites, especially nano satellites (with a mass ranging between 1 and 10kg). Today, nano satellites employed by companies such as Planet, Spire etc. do not have an on-board propulsion system, hence cannot be manoeuvred. This posses a significant threat to the space environment. Additionally, as the design life of these satellites is usually below 3 years, this means more cyclical launches every few months to maintain a constellation that satisfies their business needs, thus far these two organisations (Planet and Spire) have launched a total of 568 satellites[12].

From a Polish EO industry perspective, SatRevolution is developing the Real-time Earth observation Constellation (REC) aims at providing Earth Observation services supported by the use of a deployable telescope capable of providing 50cm resolution imagery. The first batch of the constellation is planned to be launched in 2023, with eight initial nano satellites, and should be expanded to reach 1024 satellites by 2026. When reaching its final size, the REC constellation will offer a 30 minutes revisit time which is considered as extremely frequent. The data collected by REC will serve both public and private actors in need of very high resolution and near-real time satellite imagery.

2.4 Satellite Communication

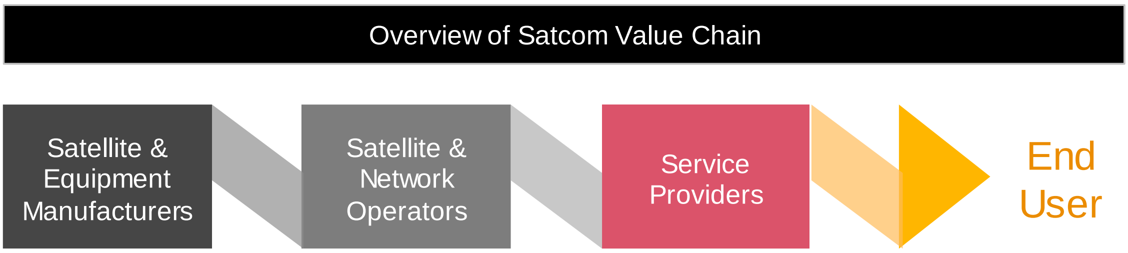
The state of play assessment described in this section maps the entities involved within the satcom ecosystem, both international and Polish. The section also provides an indication towards the market dynamic at play, and the implications of constellation-based business model on aspects pertaining to space sustainability and safety.

2.4.1 Overview of the value chain

Satellite & equipment manufacturers, satellite & network operators, and service providers are the three critical elements that define the satcom value-chain, and this is illustrated in the figure below.

[12] Available at: https://www.nanosats.eu/

Figure 5: Overview of the Satellite Communication (Satcom) value chain



The fist element within this value chain is of manufacturing satellites (HTS operated mostly in GEO, fixed Satellites, MEO satellites and LEO satellites) and the equipment to support satellite communications (VSATs, mobile antenna, fixed antenna etc). Traditionally, satellite operators would rarely move up the value chain. However, today this scenario has changed, satellite operators are moving up the value chain and manufacturing their own satellites, and in some cases they are also partnering with equipment providers. Prime examples of these are Starlink, OneWeb, Kuiper (LEO constellation by Amazon). From a Polish perspective, organisations such as SCNTPL and PZL (Airbus company) are two main organisations that assist in developing communication satellites, however, none of these companies are primes.

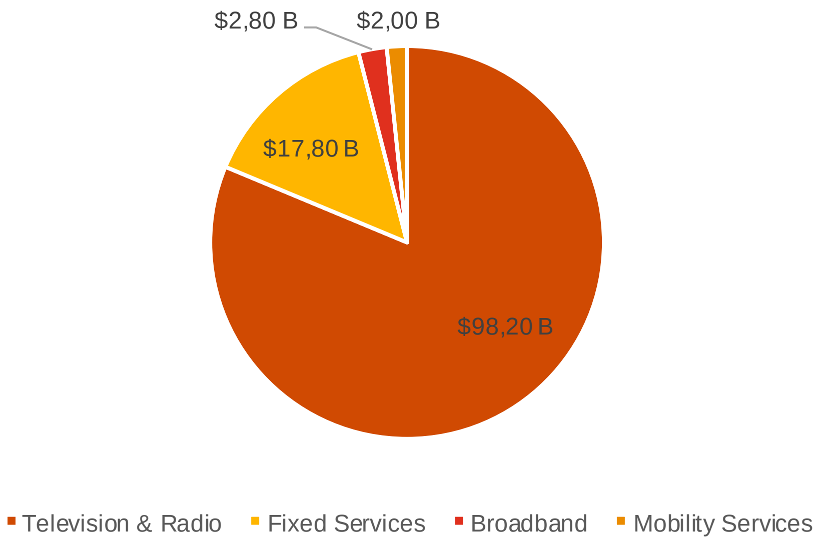
The second element within the satcom value chain is of satellite and network operators. The USA and EU member states are the two prominent regions with a large number of satellite operators. For instance organisations such as Globalstar, Iridium communication, Orbcomm, Intelsat, ViaSat, Starlink, Kuiper etc. are examples of prominent satellite operators based in the USA. While organisation such as, Eutelsat (France), SES (Luxembourg), Hispasat (Spain), Inmarsat (UK), Inmarsat (UK) are examples of prominent satellite and network operators within the European Union. In addition to this it is also critical to highlight that in 2019, Intelsat, Eutelsat and SES cumulatively attained a market share of 47% for leasing C, Ku, and Ka-Band TPE's globally. Viewing this value chain element from a Polish perspective, it is seen currently, Poland employees' foreign satellites to serve its needs. Nevertheless, a Polish state-owned company, EXATEL, plans to deploy a communication satellite to reinforce the communication infrastructure of the country[13].

The third element within the value chain is of service providers, organisations such as Global Eagle, GoGo, SITAONAIR, Thales, Iridium etc. are the entities that provide the last mile connection to the end users. In Poland, EXATEL could also become a part of this value chain with its upcoming satellite which could be backhauled by local telecom operators for 5G services, while also being used to serve the mobility markets (land, maritime and aeronautical satcom)

The satcom market is by far the largest space market, with global service revenues reaching USD 120.7B in 2019 with the following market shares[2]:

[13] https://scienceinpoland.pap.pl/en/news/news%2C82471%2Cexatel-launch-polish-satellite-about-three-years.html

Figure 6: Global satcom revenues in 2019, segmented by satcom applications



In addition to this, the global equipment market reached revenues of USD 32.9B with the following market shares[2],

- Consumer equipment: 54% (USD 17.9B)
- Network equipment: 46% (USD 15B)

2.4.2 Market Dynamics

The satcom service market is composed of four majors vertical, television and radio, fixed services, broadband services, and mobility service. From a market perspective television and radio represent a large share of the market today too, approximately 81% in terms of global satcom revenues. However, this market has been steadily declining over the years due to,

- Cost of terrestrial bandwidth getting lower.
- Constantly rising bandwidth consumption.
- Movement away from TV and towards Over-The-Top (OTT) content or streaming content (Netflix, Amazon Prime, Youtube etc.)

As such forcing operators to look for opportunities elsewhere. All major traditional and newspace satellite operators are trying to expand and grow connectivity verticals such as mobility (land, aero and maritime) and broadband. Nevertheless, some operators (viasat, SES, Inmarsat) are more focused on mobility markets, and some operators (Huges, Eutelsat) are more focused on broadband markets. To capture these markets, all of these operators have launched several HTS that in some cases pack 100 times more throughput and capability. However, both these markets are highly competitive and oversupplied with capacity. For instance, the launch of Viasat-1 in 2011 alone provided more capacity over North America than all the other satellites operating over that region at that time.[14] Furthermore, It is approximated that Viasat-1 achieved 1/20th of the cost per Gbps compared to other satellites with similar mass and power capabilities. The oversupply of capacity via HTS has also led to a massive slump in transponder pricing, from $1.6M in 2010 to $1.1M in 2017.[15] While this is the current status, the advent of LEO mega constellations is expected to further add more capacity to these markets, and further direct the prices downwards.

On the demand front, pre-covid19 pandemic, mobility markets such as land-mobile, aero-satcom, and maritime-satcom were providing positive demand and growth indications.

[14] Available at: https://spacenews.com/viasat-says-viasat-2-business-plan-intact-despite-antenna-glitch/
[15] Available at: NSR's Global satellite Capacity and Pricing Market Report

Maritime Market

In the Maritime market, between 2017 to 2018 over 7,700 vessels adopted broadband connectivity, as such nearly doubling the installation rates from 2016 to 2017. The demand drivers in this market are safety and reliability rather than entertainment. This is represented by the market penetration rate which is the highest in off-shore vessels at 96%, followed by 51% in merchant vessels and about 24% in passenger vessels, 15% in cruise ships and 2% for fishing fishing.[16]

Land Mobility market

The Land Mobility market is seeing connectivity contracts from train operators in Spain (Renfe Operadora), and in France (SNCF), such contracts are more so for entertainment purposes rather than safety concerns. Likewise, the motivator for connected buses is also entertainment to a certain extent, and the demand for such connection is dependent on regional connectivity i.e where there is a lack of terrestrial connectivity. An example of this is taking shape in Latin America, via a partnership between Hispasat and Phasor. Conversely for connected cars the demand drivers are safety and reliability and therefore a vast majority of installations are seen to take place on emergency responder type vehicles- ambulances, police vehicles, military vehicles.

Aeronautical Connectivity market

The Aeronautical connectivity market is seeing many airliners opting to take-up In-Flight-Connectivity (IFC) services, this is evidenced by the current backlog of approximately 3000 aircraft (wide-body and narrow-body) that are to be outfitted between 2019 and 2020. The prospective demand for this market majorly arises from the fact that more and more passengers (business and leisure travellers) are demanding inflight Wi-Fi over In-Flight Entertainment[17], and some of the passengers are also factoring the availability and quality of Inflight Wi-Fi while choosing airline operators to fly with. Likewise, the luxury travellers (private jets) are naturally gravitating towards operators that offer IFC

Moreover, it is also critical to note that entertainment-based connectivity is these markets are both data and bandwidth intensive, and as such required broadband connection. Conversely, certain emergency application can be facilitated by narrowband connectivity (mostly provided by nanosatellite operators such as Sky and Space Global) too.

With this view of the market dynamics in place and given the fact that Poland is yet to launch its own satellite for communications purposes, it may be fair to suggest that there is ample opportunity for Poland to develop a satellite that meets not only the current market needs locally, but also become an international player within the satcom market.

2.4.3 Regulatory Environment

International, European and domestic regulations of satellite communications

The regulation of satellite communications is widely regulated, at the international level, by the International Telecommunications Union (ITU) and the allocation of frequency spectrum and orbit usage. In addition, several domestic laws will apply at country level and ensure compatibility of different spectrum usage. These domestic regulations are here to ensure that spectrums are properly allocated within players of the industry as well as between the civilian and the military domains.

ITU regulations form an independent legal regime, however, the major principles are based on the UN Declarations and Treaties as well as paragraph No. 196 of Article 44 of the ITU Constitution[18].

[16] Available at: https://www.nsr.com/a-1st-order-solution-more-broadband-maritime-vessels/
[17] Available at: https://www.inmarsataviation.com/en/benefits/passenger-experience/air-travellers-see-inflight-broadband-as-an-essential-freedom.html
[18] http://search.itu.int/history/HistoryDigitalCollectionDocLibrary/5.22.61.en.100.pdf

UN Declarations and treaties relevant in the field of satcom regulations include:

- The Outer Space Treaty (1967)
- The Liability Convention (1972)
- The Registration Convention (1976)
- The "Declaration of Legal Principles" that govern the activities of state sin the Exploration and Uses of Outer Space (1963) later codified in the OST 1967
- The "Broadcasting principles" of 1982 that govern the use by States of satellites for international direct TV broadcasting

The ITU Constitution, in its Article 44 specifies that "In using frequency bands for radio services, Members shall bear in mind that radio frequencies and any associated orbits, including the geostationary-satellite orbit, are limited natural resources and that they must be used rationally, efficiently and economically, in conformity with the provisions of the Radio Regulations, so that countries or groups of countries may have equitable access to those orbits and frequencies, taking into account the special needs of the developing countries and the geographical situation of particular countries".

In addition, the governance of frequency spectrums and use of orbits also follows the legal regime based on the ITU Constitution and the ITU radio regulations. They regulate the following elements of satellite communications:

- Spectrum allocations to different categories of radiocommunication services
- Rights and obligations of member administrations to obtain access to the spectrum and orbital slots
- International recognition of these rights by recording frequency assignments and, as appropriate, orbital positions used or intended to be used in the Master International Frequency Register.

At the European level, the Telecom Directive (2009/140/CE) is the prime regulation resulting from the so-called "Telecoms Package" adopted in 2008 and 2009 by the European Parliament. The lot of reforms notably created the Body of European Regulators of Electronic Communications (BEREC) that in oversees the actions of all the national regulators.

Finally, at domestic level, satcoms are regulated by laws and regulations, and are often in the hands of a regulator that is either independent or an agency under the authority of the state.

2.4.4 Perspectives

It could be hypothesised that in the upcoming decade there will be a wide variety of satcom business model, and the idea of LEO mega constellations being a part of this combination seems like a possibility. Having said that, it is also true that the most challenging case would be for small LEO's. As in the upcoming decade they will have to mass produce and launch 1000s of satellites, develop ground infrastructure that is compatible with fast moving LEO satellites. In addition to that traditional space operators, could further experience a major transition from legacy fixed and mobile satellite services (FSS and MSS) toward High Throughput Satellites (HTS) markets:

- The non-HTS market could shrink at a CAGR of -5.5% over the period 2019 – 2029, going from a market of US$ 10.5 B in 2019 to an expected size of US$ 5.9 B by 2029. However, Small GEO operators could play a critical role in addressing the traditional markets, as small GEO satellites are expected to be considerably cheap therefore requiring comparatively less CAPEX.
- HTS markets are expected to explode in the future, with the HTS satellite taking over legacy FSS and MSS satellites. By 2029, HTS, could represent 77.4% of the overall satcom market. The HTS market is expected to be driven by the tremendous growth of broadband access (i.e. satellites services B2C) with a CAGR of 20.9% over the period 2019 – 2029). The remaining growth of HTS is expected respectively by the very interesting growth of enterprise data (i.e. fixed satellite services B2B), commercial mobility (i.e. mobile satellite services B2B, including maritime and IFC) and satcom services for Governmental & military applications.
- HTS could be driven by legacy business and positioning of satellite operators in GEO, but a strong growth is expected from non-GEO HTS business models, mostly driven by LEO constellations.

As mentioned previously, the satcom market and the players within this market are poised to launch thousands of satellites in the coming years. This shall become a major concern for safe operations in space.

In terms of regulations, the ever-growing number of small-sats expected to orbit the Earth due to the rise of mega-constellation projects will require updates in satellite communications regulations. This might impact ITU regulations through new rules of orbital slots allocation, that will need to be re-allocated more often in case of no-usage and as such will certainly lead to a growing number of slot sales which will also need to be more thoroughly regulated in the future. Because additional frequencies will be required in the future, we expect the ITU to intervene in this field as well and we might see new regulations on new frequency bands in the future. Overall, we foresee that the issue of orbital slots and frequencies allocations will be a hot topic in the coming decades. In addition, the ITU might have to take on a new role as a regulator of deep-space telecommunications regulator in a context where there is an increasing demand for deep-space telecommunication gateways to facilitate telecommunications between the Earth and outer space outposts, including on the Moon.

2.5 Satellite Navigation

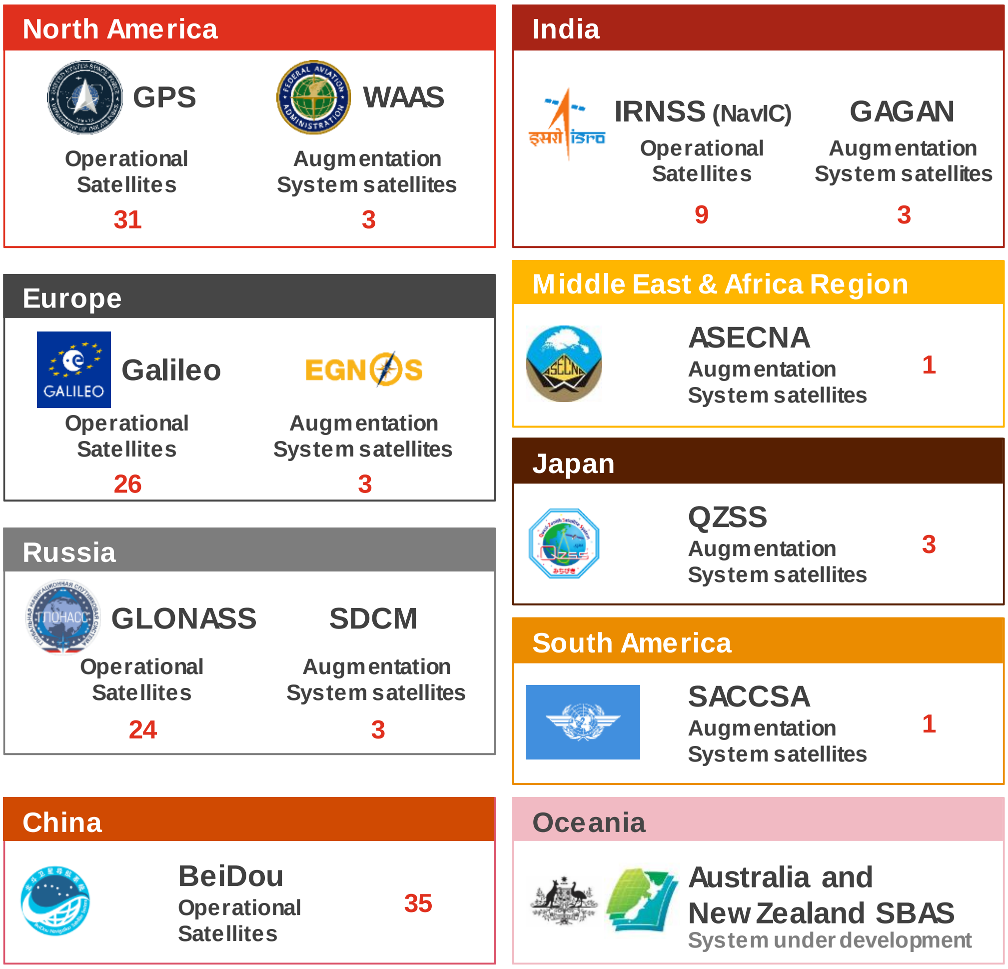
Global Navigation Satellite System (GNSS) satellites provide information about positions, routes, speed and timing, and are used by an extremely wide range of users in every economic sector. Navigation signals are freely emitted by public entities, and their exploitation drives significant economic activity.

GNSS signals are provided by a variety of global constellations (i.e. US GP, Russian Glonass, European Galileo, Chinese Beidou) but also regional systems (i.e. Japanese QZSS, Indian IRNSS, Chinese Beidou regional component) and Satellite-Based Augmentation Systems (SBAS). The latter are used to improve the accuracy and reliability of GNSS information by correcting signal measurement errors. SBAS has been implemented by various countries, in the US with the Wide Area Augmentation System (WASS), in Europe with the European Geostationary Navigation Overlay Service (EGNOS), in Japan with the Multi-functional Satellite Augmentation System (MBAS), but also in India and Russia. The benefits it presents encourage new countries to develop their own SBAS, including Australia and New Zealand that plan to develop it by 2023[19].

The following figure provides an overview of the existing satellite navigation systems:

[19] Satellite Based Augmentation System (SBAS) for GIS and mapping users, ESRI Australia (12 March 2020) https://esriaustralia.com.au/event/satellite-based-augmentation-system-sbas-gis-and-mapping-users

Figure 7: Overview of existing Global Navigation Satellite Systems and Infrastructures



2.5.1 Overview of the value chain

The GNSS value chain is similar to the value chains characterising other satellite domains and applications, as it follows three main type of activities (Satellite and ground system manufacturing, satellite operations, and service provisions).

The specificities of the GNSS value chain compared to other satellite domains are found in the downstream segment mainly. The GNSS value chain is composed of three streams:

- The upstream includes all actors involved in the design, integration and testing of the satellite systems and ground stations.
- The midstream covers all activities related to the operation of the navigation system, ensuring the delivery of PNT services.
- The downstream sector involves the set of activities related to the exploitation of the satellite navigation system and the provision of value-added products and services to end users.

2.5.2 Market Dynamics

The development and operations of satellite navigation systems drive economic and commercial activities which are dependent on GNSS technologies. The main applications supported by GNSS infrastructure are the following:

- **Road:** Intelligent and automated vehicles are supported by satellite navigation services
- **Manned Aviation:** The safety of commercial and manned aviation ensured by Air Traffic Management significantly relies on navigation satellites

- **Drones:** Both consumer and commercial applications based on drone technology are enabled by GNSS.
- **Maritime:** The positioning of ships in seas and oceans is supported by GNSS
- **Emergency Response:** GNSS is key to support the efficiency of Search and Rescue applications to provide support to people in danger or distress.
- **Agriculture:** Precision farming facilitating agriculture activities as well as agri-logistic are enabled by GNSS
- **Geomatics:** Geomatics is the collection, storage, analysis and disseminating of geographic information coming from multiple sources of data including remote sensing and GNSS.
- **Critical Infrastructures:** GNSS supports the efficiency and reliability of a set of vital and critical infrastructure such as telecommunications applications, energy applications and finance applications by ensuring accurate time.
- **Consumer Solutions:** Connected devices such as smart phones, personal tracking devices, wearables, etc. rely on the combination of 5G, IoT and GNSS capabilities, and drive a growing market.

The Global GNSS market is expected to double within the next ten years

According to Issue 6 of the GNSS Market Report, the global revenues generated by GNSS based activities reached EUR 150.7 Billion. This same report projects that global revenues generated by GNSS based activities will double by 2030.[20] The global GNSS market is therefore experiencing a significant growth which is mainly driven by multiple factors such as digitalisation, artificial intelligence, Internet of things and big data capabilities. The development of the smartphone market which enables a large number of GNSS-based applications seems to have reached maturity in the North American, European and Asian market, but is still significantly growing in developing countries. This driver is expected to further increase the overall market growth of the GNSS market.

The European GNSS market

At European level, the market is fostered by the use of Galileo and EGNOS, which is reaching Full Operational Capability and is expected to provide Europe with an independent GNSS infrastructure. Additional features offered by Galileo such as the return link service are expected to be key differentiators of the European system and will bolster the competitiveness of European based applications. According to Issue 6 of the GNSS Market Report, the European revenues generated by GNSS based activities reached EUR 38.4 Billion in 2019 and are forecasted to reach EUR 65.3 Billion by 2029[21].

Poland plays a key role in the EGNSS infrastructure

Poland plays a key role in the EGNOS infrastructure by hosting a Ranging and Integrity Monitoring Station (RIMS) in Warsaw, in the Space Research Centre of the Polish Academy of Science. Poland's implication within EGNOS both serves the efficiency of the system and benefits Poland agricultural sector by offering precision farming solutions.

At downstream level, Poland is participating to the development of several applications through E-GNSS H2020 calls. Poland counts two leading coordinators and ten project partners in the frame of E-GNSS H2020 calls. The following table provides a sample of the Polish companies participating to E-GNSS H2020 calls:

[20] GNSS Market Report, Issue 6, 2019 https://www.gsa.europa.eu/system/files/reports/market_report_issue_6_v2.pdf
[21] [21] GNSS Market Report, Issue 6, 2019 https://www.gsa.europa.eu/system/files/reports/market_report_issue_6_v2.pdf

Table 4: List of EGNSS H2020 projects involving the participation of Polish entities (non exhaustive)[22]

Project Name	Market Application	Project Cost	Polish involved in the project
CaBilAvi	Aviation	1 879 675,00 €	Kosmonauta.net sp. z o.o.
MOBNET	Location Based Services (LBS)	1 242 533,00 €	Szkola Glowna Sluzby Pozarniczej
FLAMINGO	Location Based Services (LBS)	1 999 793,00 €	Blue Dot Solutions sp. z o.o.
GALENA	Road	1 267 240,00 €	IGIK
SARA	Search and Rescue	1 455 583,00 €	AKADEMIA MORSKA W SZCZECINIE AM
DEMETERA	Timing & Synchronisation	4 366 061,00 €	ELPROMA ELEKTRONIKA Sp. z o.o.

In addition to the participation to EGNSS projects, Poland is also developing key applications for which GNSS play a key role. Indeed, Poland is specialising in the Drones domain, which became the third market segment for device shipments according to the latest GNSS market report (Issue 6).

The POSITION H2020 project (Polish Support to Innovation and Technology Incubation) aims at fostering the market development and uptake of GNSS initiatives and activities in Poland through the creation of a network of Polish actors composing the national GNSS sector.

2.5.3 Regulatory Environment

Because GNSS is largely under the control of military authorities, except for Galileo, it is difficult for civilians to regulate new developments in the field of satellite navigation. As such, most of satellite navigation operates at the national level, with each country enacting national laws and regulations for his navigation system and its complementary GNSS augmentation service like EGNOS for Galileo. Galileo, due to its European nationality is regulated by the European Union.

International Law provides regulatory frameworks for Satellite Navigation

International regulation of GNSS is based on the international space law treaties corpuses, including Outer Space Treaty (1967), ITU regulations and other sectoral regulations like the International Civil Aviation Convention (Chicago Convention) or the International Maritime Convention.

These international regulations apply to the responsibility of GNSS provider States for activities in outer space (OST Article VI) as well as the registration requirements that must comply with the United Nations' registration convention (1974). Under the latter, GNSS satellites must be registered in an appropriate state registry by the launching state, following the UN registration convention.

States and all their nationals have a free right of access to GNSS services. This results from a 1998 resolution adopted by the ICAO Assembly, stating that all States "shall have access, on a non-discriminatory basis under uniform conditions, to the use of GNSS services". Despite ICAO resolutions not being endorsed with the legal authority of a treaty, and being limited to aviation, this sets a precedent in the common practice behind GNSS services and the idea that it should be seen as a non-excludable public good.

Finally, because GNSS operates entirely by transmission of positioning, navigation and timing information by radio frequencies, they also respond to ITU regulations and operating states must file proper requests for slots and frequency allocations.

[22] GNSS Market Report, Issue 6, 2019 https://www.gsa.europa.eu/system/files/reports/market_report_issue_6_v2.pdf

Towards more multilateral cooperation in Satellite Navigation

There have been several initiatives towards a greater integration and coordination of GNSS worldwide, largely under supervision of the United Nations. International coordination and interoperability of GPS takes place in the UN International Committee on GNSS (the ICG) and its several thematic subgroups. International coordination of GNSS within the UN ICG is voluntary, but motivated by necessity, as it is in the self-interest of GNSS providers to know about each other and help each other. Overall, more cooperation and interoperability leads to better accuracy, thus in the interest of all players.

This trend has been observed in all major GNSS countries, including that US, where the 2010 US National Policy Statement, clearly engages the country in cooperation with foreign GNSS providers to encourage compatibility and interoperability. In addition, bilateral negotiations between GNSS systems providers also facilitate coordination on cross-platform specific issues. Example of bilateral agreements exist, such as the agreement on coordination of GNSS issues between the USA and the EU (2004) that includes 4 working group established.

Satellite Navigation coordination efforts remain exposed to unilateral hard law decisions

It should be pointed that the previously mentioned initiatives mostly represent soft law instruments that are voluntary-based and are therefore exposed to changes in hard law doctrines. Such an example is the decision by the US Congress in 2013 to forbid the installation of Russian GLONASS monitoring stations in the US soil, therefore hindering the efficiency of the GLONASS GNSS system, thereby limiting factual coordination efforts. This is a direct result from the mostly military-based nature of GNSS activities that will forever remain under the direct scrutiny of national lawmakers.

Standardization in the GNSS segment

As stated by Article 14 of the regulation No 1285/2013 on the on the implementation and exploitation of European satellite navigation systems, The EGNSS agency (GSA) is in charge of standardization and certification activities related to the Galileo and EGNOS programs. The GNSS segment, for its upstream part, has thoroughly followed standardization measures proposed by the ECSS. This is due to the technical compliance of Galileo satellites with the ECSS standards.

On the other side, it is important to note that standards also apply to the downstream part of the satellite navigation market. This standardization is a result of the global coverage of the Galileo program, which pushes the GSA towards an alignment with the different stakeholders of the various market segments of satellite navigation. The main GNSS domains of application where a potential for standardization exists include:

- The aviation market, with Surveillance and Search & Rescue features. The Automatic Dependent Surveillance – Broadcast system (ADS-B) the surveillance technology utilized to track and determine the position of an aircraft by satellite navigation is standardized at global level through the ICAO. Regarding Search and Rescue, the main regulations and requirements in this field are issued by the international COSPAS-SARSAT program, which has developed a satellite-aided search and rescue system to detect beacons on aircrafts, ships and individuals. Hence, the GSA and the COSPAS-SARSAT have to define an efficient set of standards for the use of the Return Link Service within Search and Rescue in order to maximize the efficiency of RLS.
- With regards to the Maritime market segment, EGNSS can be used for E-navigation, which consists of optimizing data exchange and communication on ships and on shore to improve the safety of commercial shipping. E-navigation is made possible with the use of a Positioning, Navigation and Timing (PNT) receiver. However, it appears that the integration of PNT needs to be standardized, especially concerning user use of the device. Another area in the maritime domain that needs to be consolidated in terms of standardization is autonomous vessels. While this use case is expected to grow in importance in the coming years, no standardization process in this area has been initiated so far.
- The Road market segment is the largest GNSS downstream domain. Its applications include the equipment of a GNSS receivers into vehicles, and therefore requires the definition of suitable processes for device integration and usage. The eCall regulation is one of the most

important achievements in the field of standardization and certification in the Road market segment. As per this regulation, all new cars and small-sized vans since April 2018 in Europe must be equipped with the eCall emergency system which is based on the EGNSS signal. However, several road applications are yet to be supported by standardization practices.

Finally, location Based Service (LBS) applications include two main use cases requiring the implementation of standardization measures: Internet of Things (IoT) and 5G networks. Standards regarding the use of IoT within the GNSS system only cover the use of location information, but do not yet cover reliability of positioning nor processes to be followed when handling data. Regarding 5G, standardization is ensured by the International Telecommunication Union (ITU) and is currently in progress.

2.5.4 Perspectives

It is expected that the GNSS market will to continue to expand in the next 10 years, both with devices and services. Indeed, as the world economy and society are expected to be massively digitized in the next decade, technologies relying on GNSS for position, navigation and timing are also expected to expand in the future. Another macrotrend that is expected to boost the use of GNSS is the climate change, as it will require more sustainable ways of doing in many sectors, spanning agriculture or mobility, but also emergency response. The silver economy is another driver that is expected to push the use of GNSS, as the need for new services should increase with the surge of Location-Based applications (e.g. mobile health, wellness) dedicated to elderly people.

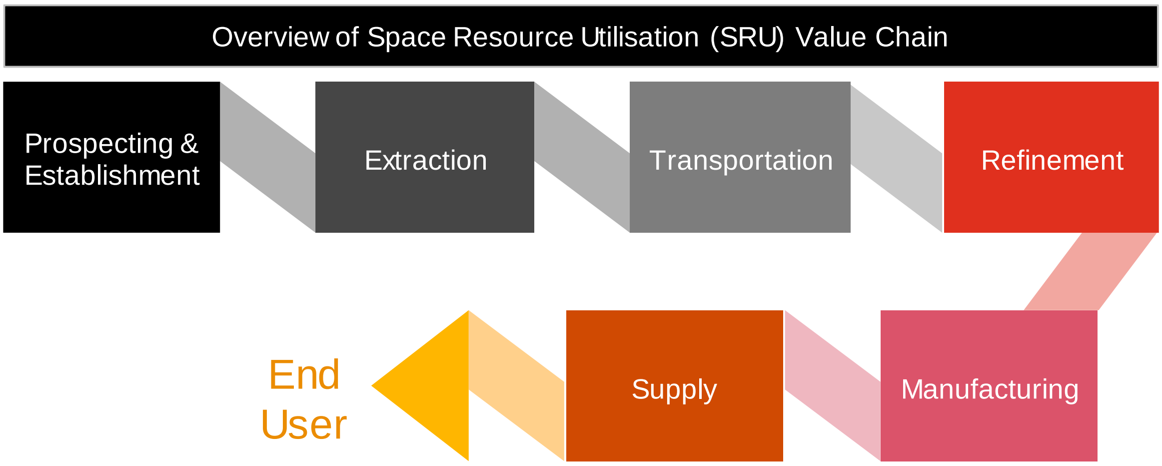
2.6 Space exploration and Space Resource Utilisation

The idea and concept of utilising space resources for commercial purposes has become a topic of significant interest within the space industry since the enactment of USA's Space Resource Exploration & Utilisation Act of 2015. Keeping this in mind, the following section views SRU and its inherent value-chain from a market perspective, thus identifying the current trends and challenges faced by this market. Based on this a brief perspective into the future evolution of this market along with its implications on space safety and sustainability is also highlighted.

2.6.1 Overview of the value chain

The value chain that depicts space exploration activities, especially the activity concerning Space Resource Utilisation (SRU) is deemed to be in its infancy. However, PwC has utilised the terrestrial mining industries value-chain and has built upon it to develop a SRU value-chain as depicted in the figure below.

Figure 8: Overview of the space exploration value chain



Recently there has been a significant movement within the space industry to explore and exploit space resources on the Moon, Mars and eventually Asteroids. Traditionally, space exploration has been an activity that was conducted by states or their relevant governmental agencies (example: NASA, ISRO etc.). Today, the situation has significantly changed, and this is largely due to commercial interest in mining resources in outer space, led by the dot com billionaires. While this is a very new market, and a lot of segments within its value chain are not firmly established, the following is the perceived value-chain that organisations aiming to exploit space resources shall have to abide to. There are seven stages to this value-chain, and they are as follows,

1) **Prospecting & Establishment:** It is the first step to analyse and understand the geological environment of celestial bodies. This stage of the value chain focuses on developing technologies that can perform prospection both remotely via the use of orbiters, and in-situ on the surface of the Moon, Mars or asteroid. For SRU, establishment would include the selection of the most favourable celestial body to be resourced, the particular targeted location on that body according to the feasibility and resources of interest, and maintaining access to it by sending the assets selected to be most convenient for the operations targeted.
2) **Extraction:** Extracting operations include digging, drilling and recovery. Particular technologies and methods would be required to extract resources on extra-terrestrial bodies depending on the structure, composition, and types of resources available on these bodies.
3) **Transportation:** In space mining activities, transportation is a concern even before extracting resources and all along the value chain. It involves the transportation of spacecraft to required orbits and the transportation of resources from one location to the other i.e. from one point on the moon to another, from the Moon to a fuel depot or from a fuel depot to LEO etc.
4) **Refinement:** Refinement activities designate the processing of the material excavated in the extracting phase, to transform it into a usable or sellable product. The refinement process aims at reaching a sufficient level of purity for the resources, be it water (for instance to be drinkable or to serve as propellant) or metals (to be able to manufacture from it).
5) **Manufacturing:** Manufacturing is the transformation of any type of input materials (usually from the refinement process, but it can also be direct inputs such as the raw regolith) into a product or a structure. In the frame of SRU, manufacturing would mostly apply to metals and regolith (potentially to plastics in the longer term) to obtain mechanical parts or walls.
6) **Supply:** The supply stage designates the delivery of the final products to the users and customers. This can be delivery of the parts and structures locally (for extra-terrestrial bases), back to Earth, or in space. For the latter, it can be to supply space stations or satellites, but it can also include the storage capabilities such as for propellant (fuel depots).

Given the fact that this market is still under development, it is largely being carried forward by start-ups, and a vast majority of them are based in the USA. In 2018, NASA performed the selection of a set of 10 national companies to foster initiatives in the field of Space Resource Utilisation. The Advance Space Resource Collection programme is designed to support companies with the conduction of studies for the development of technologies to collect, process and space-based resources for lunar and Mars missions. The programme is organised under three tracks. The first track aims at supporting one-year studies examining the different technology gaps related to SRU and identify the benefits related that could be expected from the development of gap filler concepts. The second and third tracks focus on technology development and demonstration during a period of at least 42 months (three and a half years), with the third track specifically focusing on subsystem and subcomponents development and testing.

The following are examples of US companies developing SRU concepts:

- Blue Origin
- United Launch Alliance
- University of Illinois
- UTC Aerospace Systems
- Blaze Tech Corporation
- Paragon Space Development
- Skyhaven System
- Teledyne Energy Systems
- Honeybee Robotics Spacecraft Mechanisms Corporation
- OxEon Energy

Followed by European countries such as Luxembourg, Germany, UK etc. Some examples of European entities involved in SRU initiatives are, Odysseus Space, Rethink Robotics, PT scientist etc.

From a Polish perspective, there are no prominent organisations or start-ups venturing directly into space mining. However, Polish organisation such as ABM Space, Astronika, PIAP Space, SENER, SKA Polska etc. are examples of companies that are developing automation & robotic technologies that could be utilised to supply specialised parts and systems to the organisation that plan of developing orbiters, landers and rovers aimed towards activating elements within the SRU value chain.

2.6.2 Market Dynamics

The demand for space exploration is still being funded by government agencies, a prime example of this is the Artemis Program that aims to land the 1st women and next man on the Moon by 2024. This is ultimately to facilitate the USA's goal of developing sustainable presence on the Moon, and then eventually expand towards Mars. However, USA via its Artemis program aims to include private sector organisations to also shoulder some responsibility and develop technologies that could assist in better exploring the Moon. The commercial Lunar Payload Services (CLPS) program is aimed at just doing that, where the idea is NASA shall procure a vast majority of the mass budget on the landers and rovers, while leaving some capacity for the private sector to experiment and prospect the opportunities in the south pole of the moon. In terms of competition, there are already 14 companies within the market that bid towards CLPS contracts, and thus far only three organisations have secured contracts. It may be fair to say that the market for SRU and lunar transportation is already over-crowded.

In addition to the companies in the USA, organisation in countries like India, Israel, Japan and some EU member states (Luxembourg, UK, Germany, etc.) are also eyeing commercial opportunities to explore and exploit resources on the Moon. In 2019, ESA and its Member States agreed to develop a European .lunar lander encourage the European ecosystem of space actors to develop technology and concepts in the field science and robotics. In addition, ESA will develop a European Service Module in the frame of the Artemis programme developed by NASA. ESA is expected to invest a €1.953 billion in the development of human and robotics exploration space exploration activities within the 2019 – 2022 timeframe. China has recently recovered lunar samples following the successful completion of the Chang'e-5 mission. The mission successfully collected a 2 kilograms sample of Lunar elements that will be subject to scientific analysis in a dedicated laboratory in Beijing. The collected sample is expected to be the oldest piece of lunar material ever collected.

Lastly, in terms there are several barriers towards entering this market, the most significant is the technological barrier. As thus far there are no commercial organisations that have successfully landed on the Moon. The only commercial mission that has been launched was Beersheet (SpaceIL) from Israel, which crash landed onto the lunar surface. Moreover, since this accident SpaceIL has cancelled its plans of launching a second lunar lander. Additionally, for none-US based organisation securing a contract from NASA is close to impossible until and unless the organisations country signs the Artemis accord, therefore creating an additional barrier to entry for these nations.

2.6.3 Regulatory Environment

Space exploration is an activity that is located at the crossroads of regulatory requirements. The launch part of space exploration activities must obey traditional access to space regulations until the payload reaches its separation point.

Payloads that are used for space exploration activities must obey the main international law principles as developed in the corpus of international space law treaties and agreements, including the Outer Space Treaty (OST, 1967), the Liability Convention (1972), the Registration Convention (1976) and the Moon Agreement (1984). Therefore, space exploration payloads must not be use for militarized goals and are expected to be focused on science and research activities.

Space Resources Utilization (SRU) is a new source of regulatory challenges in the field of space exploration

Space exploration has, however, been a legal challenge over the past decade due to the increase interest in Space Resources Utilization (SRU) activities and the uncertainties around the rights awarded or not by the diverging interpretations of the Moon Agreement. There aren't many countries that have enacted SRU regulations so far, the main ones including the United States, Luxembourg and the United Arab Emirates. In the US, the Trump administration has strongly pushed in favor of SRU activities through an Executive Order encourage the recovery and use of space resources[23]. The latest advancement in terms of SRU are the Artemis Accords, a set of bilateral agreements signed between 9 space powers (USA, Australia, Canada, Japan, Luxembourg, Italy, the UK, the UAE and Ukraine) on October 13th 2020. The Accords lay down principles for cooperation in the civil exploration and use of the Moon, Mars, comets, and asteroids for peaceful purposes and base themselves on the OST 1967 while expanding on the legal grounds for space resource extraction and utilization[24].

Identification of gaps at the Polish Level

Poland does not appear to have a domestic legislation that regulates Access to Space activities. It is to be noted that with regards to International Space Law, Poland has signed and ratified the four major treaties related to space activities, including:

- The Outer Space Treaty (ratified in 1968)
- The Rescue agreement (ratified in 1969)
- The Liability Convention (ratified in 1973)
- The Registration Convention (ratified in 1978)
- The Moon Treaty (ratified in 1968)

Standardization efforts in the field of space exploration

Because space exploration often involves a collaboration between multiple space agencies, high levels of standardization facilitate interoperability of components despite design, development and manufacturing in multiple locations. This is particularly true for the European Space Agency (ESA) that assigns and coordinates missions among the different national space agencies of its partner states. Different sets of standards exist for different segments of the space exploration field:

- Upstream, with a distinction between ground segments and space objects. Standards on space objects are stricter and more important because space objects often involve higher levels of international coordination and cooperation. On the other side, ground segment assets are more often built by lower number of actors in fewer countries therefore needing less components assembly efforts and therefore lower needs of standards

- The Midstream and Downstream segments need standards pertaining to the variety of scientific missions for which assets are built and tailored. The acquisition of data is subjected to specific standards including weight & measure units of the data to other standards like software and data formats. These standards will potentially vary based on the type of scientific mission concerned, which will most likely impact standards like data format and processing software to be used.

- Finally, manned missions also have their own set of standards revolving around life support. Europe having no ongoing nor planned manned mission beside the ISS, has very little if no updated standards for manned assets

[23] Executive Order on Encouraging International Support for the Recovery and Use of Space Resources

[24] https://www.nasa.gov/specials/artemis-accords/index.html

2.6.4 Perspectives

Under a very optimistic conditions, it is estimated that the space mining market could generate up to USD 2.8B by 2025[25]. Having said that, there are several challenges (regulatory, geo-political and financial) that this market faces, and may need governments as their anchor customers to establish and sustain the SRU value-chain in the near future.

The activities conducted under the umbrella of space exploration, and mostly outward looking, and are aimed towards exploring resources on or near other celestial bodies, and as such do not pose an immediate threat to Earth or Earth orbits.

Trends in space exploration regulations tend to focus on SRU developments, as they are the main new trend in space exploration, at the crossroads with commercial exploitation of outer space. SRU regulations are increasingly being developed at national level, after being the appanage of the Moon Treaty. With challenges being brought over the Moon Treaty by States wishing to exploiting outer space resources, we see a growing number of SRU regulations being drafted by countries like the UAE, Luxembourg, possibly Japan, as well obviously as the recent efforts of the USA to deploy the legal groundings of commercialization of space resources. We expect this trend to be pursued in the future as new business cases will be built. Such new regulations will need to thoroughly articulate around concepts like the in-situ exploitation of resources for the conduct of exploration missions or the extraction for later reselling of those resources on Earth, which will probably bring life to diverging approaches to regulations.

2.7 Space Situational Awareness and Space Safety

Space Situational Awareness encompasses Space Surveillance and Tracking (SST), Space Weather (SWE) and Near Earth Objects (NEO). It refers to the capability of detecting and tracking man-made and natural threats (e.g. space debris, geo-magnetic storms, asteroids), predicting and assessing the involved risks (e.g. collision risk, storm intensity risk) and providing services (e.g. conjunction warnings, storm forecasts and alerts) and related products (e.g. tailoring data and information to the specific type of institutional or commercial users).

The state of play analysis of Space Situational Awareness proposed in this report focuses mainly on SST and Space Traffic Management. As several actions have been initiated at European and International level for the implementation of Space Surveillance and Tracking activities, Space Traffic Management appears as a novel topic that is yet to be shaped in its regulatory, governance, organisational, and technical fields. Indeed, the current concept of SST is expected to rapidly evolve in the more complex concept of Space Traffic Management. How this will be implemented is still unknown, considering that major international stakeholders (E.g. US Government, the European Union, the Russian Federation, China) have, so far, pushed forward different and conflicting implementation concepts or have not yet clarified their position.

Space Surveillance and Tracking (SST) is the study, monitoring and analysis of the evolution of space debris and other space objects. This encompasses the detection and tracking of debris and other space objects in orbit, in order to issue warnings regarding collision avoidance, debris fragmentation, and the timing and locations for re-entry into the atmosphere; as well as exchange information with operators to support them when confronted with the need to take appropriate actions such as collision avoidance manoeuvres. Space debris in the context of SST refers to man-made objects in space that have lost their functionality (as opposed to meteoroids and asteroids). Thus, space debris includes any debris from small fragments of spacecraft, resulting from break-ups, in-orbit collisions, and in-orbit explosions, up to discarded rocket bodies and inactive satellites after completion of their operational mission. As such, space debris is mostly present in those regions of space closer to Earth, such as the LEO, MEO and GEO regimes that

[25] Space Mining Market by Phase, Asteroid Distance, Commodity Resources, and Geography, Available at: https://www.marketsandmarkets.com/Market-Reports/space-mining-market-129545886.html#:~:text=The%20space%20mining%20market%20is,at%20a%20CAGR%20of%2023.6%25.https://www.marketsandmarkets.com/Market-Reports/space-mining-market-129545886.html#:~:text=The%20space%20mining%20market%20is,at%20a%20CAGR%20of%2023.6%25.

are exploited for scientific, governmental and commercial purposes. LEO is utilized primarily for Earth Observation activities, and is often especially used for satellite communication with the deployment of new constellations. MEO's main usage is for navigation (Galileo, GPS, Glonass, etc.), whilst GEO is primary dedicated to Communication activities. The density of debris is also higher in specific areas of intense space activities, such as LEO at 800 km. Since space debris in LEO travels typically at 7 km/sec (i.e. around 25,000 km/h), even a small debris item of around 1 cm in diameter holds enough kinetic energy to cause a partial or complete satellite loss in case of an in-orbit collision, depending on point of impact. Debris shield technology is only effective for debris up to about 2 cm in diameter, and due to cost and complexity have only ever been installed on manned spacecraft, such as the International Space Station, and not on other types of spacecraft. Thus, most spacecraft operators can only avoid the potential consequences of a space debris collision by performing a debris avoidance manoeuvre. To do so, satellite operators rely on SST assets (i.e. sensors such as surveillance and tracking radars, telescopes, and laser ranging stations, and operational facilities such as SSA centres or data processing centres) and on related services such as conjunction analysis and warning reports. It is also important to stress the fact that it is difficult for satellite operators to know accurately their absolute position in space. It is particularly the case for small spacecraft operators who do not have the same expertise in position calculation, nor the budget to dedicate people to this task. Therefore, SST assets, such as tracking radars and telescopes, provide satellite owners and operators with valuable information to calibrate their measurement tools and to know where their spacecraft are exactly.

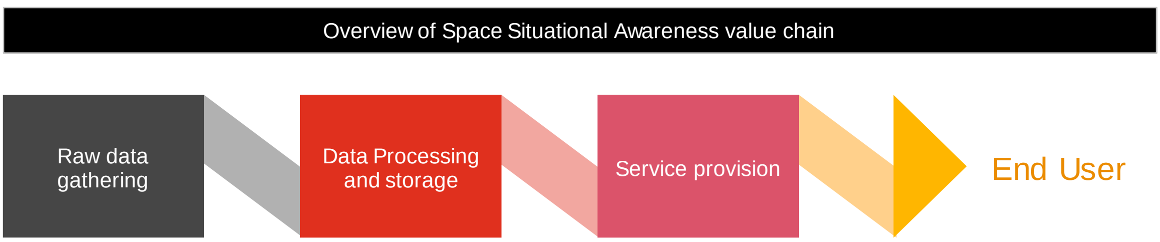
Space Traffic Management is a system of standards, requirements, guidelines, and technical programmatic and organisational activities applied to each component of the lifecycle of a space mission in order to ensure a safe access and utilisation of the space environment. STM activities are carried out by both the owner of the space mission and external entities, which play a role in validating, monitoring, supervising and authorising the activities carried out during the space mission's lifecycle. Given the strategic importance of space infrastructure and considering the significant increase of space traffic expected to materialise within the next decades, involving the entrance of new actors with little or no experience in carrying out space activities in compliance with best practices and safety standards, the need to define, implement and operate a Space Traffic Management system has been identified. As several actions have been initiated at national level for the implementation of Space Surveillance and Tracking activities, Space Traffic Management appears as a novel topic that is yet to be shaped in its regulatory, governance, organisational, and technical fields. The implementation scheme of a potential Space Traffic Management system is still unknown, considering that major international stakeholders (E.g. US Government, the European Union, the Russian Federation, China) have, so far, pushed forward different and conflicting implementation concepts or have not yet clarified their position.

The current SST and STM landscape are fragmented, with multiple institutional and commercial initiatives overlapping trough the SST value chain. The evolution and integration of SST activities within STM has already started, but no clear position has emerged on what would be the future governance scheme for STM.

2.7.1 Overview of the value chain

The overall value chain characterising Space Situational Awareness activities can be broken down into four main activities as depicted in the following diagram:

Figure 9: Overview of the Space Situational Awareness value chain



The global value chain for Space Situational Awareness activities follows an information collection, processing and distribution logic. The collection of space related data is performed with different sets of observation capabilities. The processing and storage of data aims at producing SSA information products. Once the data is processed and stored, it is analysed in order to identify relevant information related to multiple aspects of space safety and security, such as the positioning velocity and attitude of the observed and tracked objects for instance. The service provision ensures that the distribution of SSA data is done in a timely and secured manner.

The initial collection of data related to the positioning, velocity, trajectory and direction of space objects is performed by sensors which may combine several sources of information (optical/radar/laser) in a multi-layer fashion. Different technologies are utilised to observe and track space objects. The following paragraphs detail the different space object observation technologies and configurations.

- **Optical sensors** function based on visible sunlight that is reflected from space objects. Optical sensors do not comprise an illuminating source during their observation activities. This implies that the optical sensors have to operate while being in the dark to observe objects which receive sunlight reflection. Optical sensors are not optimal for the observation of objects located in Low Earth Orbit. Optical sensors are mainly characterised as telescopes.
- **Laser sensors** observe objects by using retro-reflector arrays which provide very accurate range measurements. The efficiency of laser sensors is conditioned on atmospheric conditions, as good weather is required. In addition, laser sensors work best when the position of the observed objects is anticipated with complementary information regarding the object's trajectory and velocity.
- **Radar sensors** emit microwaves and receive the radiations that are reflected by observed space objects. As opposed to Orbital sensors, radar sensors can function on a 24/24 and 7/7 basis and are not impacted by atmospheric conditions. However, radar sensors decrease the power of their signals based on the distance of these emitted signals. The further the signals go, the lower their power is. Therefore, radar sensors are not as efficient as optical sensors for the observation of space objects located in higher space regions than LEO.
- **Space-based sensors** utilise optical technology to observe the presence of other space objects. As opposed to ground based optical telescopes, the efficiency of space-based sensors is not tied to atmospheric conditions and can function any time of day and night. In addition, space based sensors have the ability to closely examine specific space objects of interest if required.
- **Surveying sensors** are dedicated to the research of novel objects which are unknown and not catalogued. They usually function by scanning an orbital region of interest to collect information on objects which have not been observed before. Therefore, the configuration of surveying sensors is based on a large Field of View (FoV).
- **Tracking sensors** are utilised to monitor and updated the position, trajectory and velocity of objects that are already known. Tracking sensors are usually configured on a medium or narrow Field of Focus in order to focus on specific objects.

The following figure provides a high-level overview of the different observation sensors and configurations:

Figure 10: Overview of observation sensors technologies and configurations

Optical sensors
- Need visible sunlight
- Most relevant for the observation of objects in GEO and MEO
- Constrained by atmospheric conditions
- Based on ground telescopes and space-based optical sensors

Laser sensors
- Provide very accurate ranging measurements
- Constrained by atmospheric conditions
- Need to dispose of minimum information on object to be observed (trajectory and velocity)

Radar sensors
- Active emission of microwaves towards observed objects
- Function on 24/24 basis
- Not impacted by atmospheric conditions
- Mostly relevant for the observation of objects in LEO

Surveying Sensors
- Search for new objects that have not been observed before
- Utilised to enlarge the debris catalogue and keep it up to date

Tracking Sensors
- Used to increase the orbital accuracy of objects that have already been detected
- Monitor the trajectory and velocity of observed objects

Once raw data is collected, it is stored, processed and consolidated in order to constitute a usable piece of information. These activities rely on data repository and processing capabilities. This segment also includes activities covering the creation and maintenance of a catalogue of space objects.

Following the collection and processing of data, information related to space objects must be distributed in a timely and efficient manner in order to support spacecraft operators in their decision making process and national security entities in their intelligence needs.

2.7.2 Governance

The development and expansion of SST activities into STM are leading national and regional governments to consolidate their position and strategy in the field of SSA. Such positioning and strategies might indeed generate advantages for national and regional governments in the scope of the Space Diplomacy, as well as advantages for national industries when these are strategically pre-positioned to capture future opportunities. For all institutions, discussion regarding the development and consolidation of a mechanism supporting space sustainability under the form of a space traffic management system is still open and far from a final agreement.

The following paragraphs introduce the different positioning, strategies and associated initiatives that are being designed; examined and implemented by major institutions at global level.

The US National Space Strategy aims at answering military, civil and commercial needs

Aware of the absence of a regulatory framework for Space Traffic Management and concerned about the security and safety of their space assets, the United States have issued in June 2018, the Space Policy Directive-3 (SPD-3) identifying the modalities towards the establishment of a Space Traffic Management System.

Concerning national governance, the Directive proposes major changes. Overall, a significant part of the responsibilities and competences in relation to STM has been moved from the Department of Defence to a civil agency: The Department of Commerce. Beyond the incentive to protect its space assets and enhance the safety of the space environment, the Trump Administration also aimed at maintaining and reinforcing US leadership in space by positioning itself as the leading entity of a Space Traffic Management system. Indeed, the SPD-3 confirms the US's willingness to maintain its dominance in the space domain, as a key enabler for a strong and secured strategic position in the space domain. The US has managed to cluster the interests of the military, civil and commercial sector within a single national space strategy focusing on a strong US influence on international space activities. Such national space strategy is explicitly inclined to defend "America's interest first" and favours the cooperation and overarching of national security, commercial and civil space sectors. This scheme also aims at fostering the development US commercial actors on both the US territory and overseas. Within its National Space Strategy, the US aims to foster conducive domestic and international environment" by streamlining regulatory frameworks to support the competitiveness of the US space industry. As such, the establishment of a new regulatory framework towards the creation of an STM system is fully in line with objectives of the US's National Space Strategy.

Russia's governance scheme in the field of SSA is shared between the military and the academia domains

The Russian SSS is controlled and operated by the military and is indicative of the military strategy adopted by Russia, where a lot of importance is placed on its space assets and capabilities to counter the threats (space-based) that may arise in modern warfare situations. In addition to that, the Military Doctrine published in 2014, classifies both strategic missile defences and strategic conventional precision weapons as major military dangers to Russia. Within this context, the primary driver of the SSS is to secure and defend the Russian territory and its space assets. It is a strong belief held by the Russian military that superiority in space would be an essential element in terms of, deterring military conflicts; and having an apt defensive response to any potential offense undertaken by its adversaries.[26]

The International Scientific Optical Network (ISON) is a scientific project, with the goal of providing significant scientific output in three key areas of research: space debris, asteroids and GRB afterglows. There is cooperation with multiple observation facilities of various affiliations (e.g. Academy of Sciences, universities, scientific institutions, and private companies), spanning 14 different countries (Bolivia, Georgia, Italy, Kazakhstan, Mexico, Moldova, Mongolia, Russia, Spain, Tajikistan, Vietnam, Ukraine, USA, and Uzbekistan). It is coordinated by the Keldysh Institute of Applied Mathematics of the Russian Academy of Sciences, and has discovered at least two hundred new GEO and HEO debris that have not been reported by any governmental agency. It has been developed as an independent source of data about space objects for scientific analysis.

The Russia Federation is a key player when it comes to discussing the concept of Space Traffic Management (STM), and the governance of such a system on an international level. From a strategy perspective, Russia leverages its technical and operational prowess in conjunction with its diplomatic channels to ensure its opinion is being heard on issues associated to the governance of space activities. More recently though, Russia has been heavily relying on its diplomatic channels to shape space governance frameworks that closely align with the Federations vision.[27] An example of this is the effort Russia made at the United Nations (UN) to curb militarisation of space.[28] It is strongly believed that a similar approach is being used to implement its version of Space Traffic Management (STM). This is highlighted by the working paper the Russian Federation submitted to the UN-COPUOS in 2017, titled "Further ideas on a set of goals for achieving the Vienna Consensus on Space Security and the need for thorough reflection on the modalities of addressing the complex issues associated with space traffic management and the justifiability of the high expectations of early decisions in this area".

The working paper provides key insights into the Russian vision of STM, it is understood that the Russian Federation strongly believes in developing a space operations safety regime prior to embarking on STM initiatives and proposes an approach that is motivated by the Cosmic Study on Space Traffic Management published by the International Academy of Astronautics (IAA). In addition to that, the federation puts forward a proposal to develop an international information sharing mechanism/platform that is envisioned to be operated by the UN. Russia strongly believes that such a platform would play a crucial role towards curbing the issue of space traffic while ensuring safe operations of objects in outer space. [29]

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[26] Source: "Challenges to Security in Space", Defense Intelligence Agency (DIA), January 2019. Available at: https://www.dia.mil/Portals/27/Documents/News/Military%20Power%20Publications/Space_Threat_V14_020119_sm.pdf
[27] Available at: https://summit.sfu.ca/item/18164
[28] Available at: https://www.themoscowtimes.com/2015/12/08/un-approves-russia-led-proposal-to-limit-militarization-of-space-a51131
[29] Available at: https://www.unoosa.org/oosa/oosadoc/data/documents/2017/aac.105c.1l/aac.105c.1l.361_0.html

The following elements provide an overview of the platforms operational and technical concept,

- **Entitles to be involved** - The platform shall centralise and integrate data derived from states, international organisations, inter-governmental organisations, satellite operators, and other such entities that are proficient in performing SSA/SST activities.
- **Type of information provided** - The vision is to provide the global community with actionable information related to the objects and events in near-Earth environment.
- **Information provision by phases** – The platforms database is expected to record information related to, launched and scheduled launches of space objects; operational/functional and non-operational/ non-functional objects in orbits; conjunction of space objects (previous and predicted); re-entries of space objects (previous and predicted); fragmentation of space objects in orbit; scheduled and conducted in-orbit operations; changes of the status of a space object; and new space objects discovered by near-Earth space monitoring means:
- **Data characteristics and quality** – The information pertaining to the objects and events should be accompanied by an assessment that provides an indication towards the reliability, accuracy and comprehensiveness of the data.[Błąd! Nie zdefiniowano zakładki.]

In addition to that, the federation is of the opinion that such a UN operated platform should be created even if certain countries were to adopt the strategy of developing their own national services for sharing information on objects and events in outer space. Through this it is understood that the Russian vision is to create a multipolar space traffic framework, as such allowing the Federation to be one of the integral poles, given its capabilities in both gather and processing space traffic data.

However, the outcome of this Russian led initiative was mixed. On one hand, the proposal did not find common ground with the UN-COPUOS member states, and such was not adopted or further discussed. While on the other hand, the core principle driving the proposal, that is, the idea of integrating data and pooling resources on an international level to implement safety of space operations did resonate with both the private and public sector entities.

China holds a leading role within APSCO

In 2015, China established a Strategic Support Force (SSF) with the goal to integrate new age defence capabilities such as cybersecurity, space and energy weapons. Since its formation the SSF controls the Republics national SSA/SST activities, along with developing early warning systems. As part of the military reforms announced in 2015, China established the Strategic Support Force (SSF) to integrate cyberspace, space, and EW capabilities into joint military operations. Since 2015, it is the SSA that is in charge of space surveillance and early warning systems.

APSCO is an organisation that aims to cooperate with member states within the Asia Pacific region to develop SSA/SST. However, as illustrated in the table below, the member states are not limited to this region alone. In order to gain traction within a global context, APSCO invites non-Asia pacific countries to join the organisation as either Associate member, or as members with an observer status.

Table 5: APSCO member states and their Stakeholders[30]

Country	Membership type	Member States Organisation Involved
China	Member State	China National Space Administration (CNSA)
Iran	Member State	Iranian Space Agency
Peru	Member State	National Commission on Aerospace Research and Development (CONIDA)
Pakistan	Member State	Space and Upper Atmosphere Research Commission (SUPARCO)
Mongolia	Member State	Communication and Information Technology Authority (CITA)

[30] Available at: http://www.apsco.int/upload/file/20180703/201807031400255205.pdf

Turkey	Member State	Space Technologies Research Institute
Bangladesh	Member State	Bangladesh Space research and Remote Sensing Organisation
Thailand	Member State	The Office of National Digital Economy and Society Commission (ONDE)
Mexico	Observer Status	Mexican Space Agency (AEM)
Egypt	Associate Member	National Authority for Remote Sensing and Space Science

In lines with the Russian-led ISON network, the APOSOS network is primarily run by the civil government authorities. However, the visibility on the data sharing policy with the military/defence organisation of APSCO's member states is limited.

EU initiatives aim at improving current SSA and SST capabilities and development new ones

The European Union and its Member States decided in 2014 to network their capabilities and launch a European initiative: the SST support framework, in order to allow further autonomy for Europe in the framework of Space Traffic Management. This framework is implemented by the participating Member States in the SST Consortium, represented through their national entities: France (CNES), Germany (DLR), Italy (ASI), Spain (CDTI), and the United Kingdom (UKSA). Since 2018 and the signature of a new Consortium Agreement and Implementing Arrangement, the consortium was reinforced by three other EU Member States through their national space agencies: Poland through POLSA, Portugal through GPSST and Romania through ROSA.

Pooling national SST capabilities together, improving SST data sharing across Member States, and setting up a common SST service provision front desk, the EU SST Framework aims at consolidating SST user requirements, to guarantee European autonomy for SST matters.

No clearly defined STM initiatives are led at European level, neither by the EU, ESA, or the European Member States. Current and future initiatives mainly aim at improving current / developing new SSA / SST capabilities, mainly for technological aspects and National Security concerns. Furthermore, no clear initiative aims at developing components of STM that concern Political, Regulatory or Industrial aspects of STM implementation.

The SST Consortium provides three main functional SST capabilities to the EU Member States, EU institutions, spacecraft owners and operators, and civil protection authorities.[31] The functions are the following:

- **Sensor Function**: consisting of a network of Member State ground-based and/or space-based sensors to survey and track space objects,
- **Processing Function**: processing and analysing SST data at national level to produce SST information and SST services.
- **Service Function**: providing SST services to the EU user community such as spacecraft operators and civil protection authorities.

The EU Satellite Centre (SatCen) collaborates with the Consortium by supporting the service function and acting as a front desk, whilst the European Commission provides financial support to operational costs directly linked to the setting up the service.

Initial services currently available to registered EU SST users are:

- **Collision Avoidance (CA):** The most common of the initial services available through the EUSST initial service provision portal is the Collision Avoidance Service. This service includes an analysis of all the available information concerning a possible collision with secondary object. In particular, the CA service consist of:

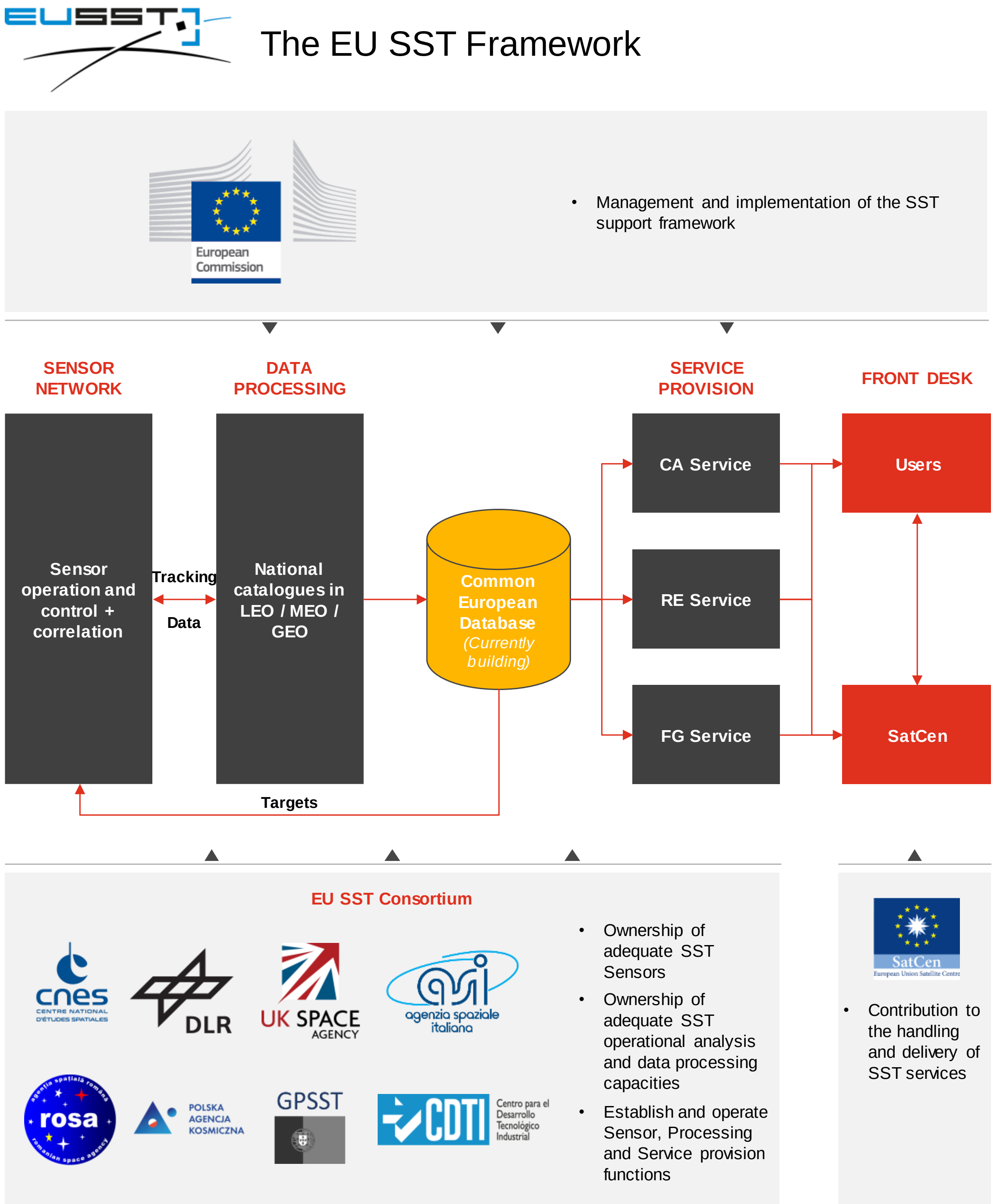
31 EU SST Website (September 2019) - https://www.eusst.eu/project/sst-decision/

  - The analysis of all the available information, including Conjunction Data Messages (CDM) from external sources, sensor data from EUSST sensors and other available information
  - The detection and analysis of Interest Events (IE) representing close approaches of space objects requiring detailed analysis due to their level of risk
  - The provision of CA products to users, together with the initiation of dialog with concerned entities to perform avoidance manoeuvres

- **Re-entry Analysis (RE)**: Re-entry analysis is a service based mainly on the US public catalogue and EU SST data of space objects susceptible to enter the atmosphere without control. The EU SST benefit is, through regular data updates, the creation of a specific warning alert only for certain categories of objects (space objects with more than 1m square RCS or a mass greater than 2000kg), which represent a threat to the European Union land area. Approved users of the service get reports under the form of list of objects likely to re-enter the Earth Atmosphere after 30 days in orbit and Warning reports.
- **In-orbit fragmentation analysis (FG):** This service aims at providing information concerning break-up or fragmentation events whenever a meaningful number of objects is catalogued. Fragmentation detection is based on the processing of CSpOC basic information (US public catalogue), and is composed of two main phases:
  - **The Short-**term FG analysis service releasing basic FG-related information to the Nominal Operation Centre
  - **The Medium-**term FG analysis service releasing more complete information once the fragments and their orbital parameters are catalogued, for two weeks following the FG event.

Additionally, most of the SST Consortium Members provide further analysis on the potential fragmentation cloud distribution and evolution.

Figure 11: The EU SST Framework Governance Scheme



Source: EU SST Framework, PwC analysis

Participation of Poland in Space Situational Awareness activities

The Polish Space Agency has signed an agreement on SSA with the US STRATCOM in April 2019 that lay the foundation for the US to share SSA information with Poland, strengthening the alliance between the two countries. Part of the agreement is the development of Polish SSA capabilities, including the development of an SSA Operations Center in order to strengthen the safety of Polish satellites (as well as from its allies) in the future.

The SSA Program of ESA, of which Poland is a financially contributing member, began in 2009 and is composed of several SSA infrastructures spread across Europe, with its HQ located in Darmstadt, Germany, within the ESOC establishment. Under ESA's SSA program, Europe is developing an independent capability to track space objects in outer space and focuses on 3 mains areas:

- Space Weather (SWE) in order to track the state of celestial bodies and their impact on space objects;
- Near-Earth Objects (NEO) in order to detect natural objects like asteroids that could impact Earth and cause damage;
- Space Surveillance & Tracking (SST), in order to watch for active and inactive satellite, rocket bodies or debris fragments in orbit around the Earth.

As previously mentioned, the Polish Space Agency (POLSA) is a contributing member of the SST Consortium developed by the European Union in order to create an autonomous SSA capability for EU Member States.

The Space Research Centre of Polish Academy of Science (CBK PAN) is responsible for leading research on near-Earth space, Solar System bodies, space technologies and associated satellite systems. The CBK PAN owns Poland's Regional Warning Center for Space Weather.

In addition, the Nicolaus Copernicus Astronomical Center Polish Academy (CAMK) conducts research in the field stellar astrophysics, binary systems, circumstellar matter, dense matter and neutron stars, black holes, accretion processes, structure and evolution of active galaxies, cosmology and extrasolar planets. The CAMK hosts activities performed under the SOLARIS project which aims at identification extrasolar planetary systems.

2.7.3 Overview of SSA capabilities

US capabilities

The United States maintains a system known as the **Space Surveillance Network (SSN)**, which includes the most complete catalogue of space objects and a large network of sensors. The data collected by the group of phased array radars, tracking radars, and space-based tracking telescopes, is sent to the **Combined Space Operations Center (CSpOC)**, which oversees a database of orbital trajectories of more than 23,000 space objects larger than 10cm. This database performs various analyses to support services, such as conjunction assessment warnings for satellite operators. Under the SSN, the US has negotiated a series of bilateral data sharing agreements, with more than 50 satellite operators, 11 countries, and 2 international intergovernmental organizations (ESA and EUMETSAT). It is also the sole entity outside of Europe that shares SST data and publishes a space objects catalogue. While being of a high quality, the warnings called Conjunction Data Messages (CDMs) are only shared based on the good willing of the US DoD. Therefore, the information procured by the US are not always exactly tailored to the operators' needs (since this is not their specific purpose). Moreover, they are often received 72 hours in advance of the event occurring which is not enough time for a proper consideration of the decision and planning of an avoidance manoeuvre, and no support and guidance is provided when avoidance manoeuvres must be performed.

The US is currently replacing its ageing ground-based radar systems with two new radar sites under the **Space Fence programme**, with one site in the North Hemisphere and one in the South Hemisphere. According to design objectives, the Space Fence system is able to survey objects up to a 2000km altitude and track objects in the LEO region. The first site deployed will focus on the portion of LEO from 550 to 2000km (where most space debris is found) and the second site will focus between 250 to 550km (where the International Space Station is orbiting at about 400km altitude). Space Fence functions as a cold start system, meaning that it tracks whatever is surveyed. The development costs of the Space Fence programme are estimated at around USD 1.6 B[32]. The Space Fence radar system reached its full-operational capability in 2019 and is expected to lead the US towards a new level of SST services in LEO. Indeed, the new US Space Fence system is expected to be able to catalogue/track about 200,000 objects in LEO, which represents an increase by a factor of ~10 compared to the current system.

Regarding optical systems, the ground-based optical systems (e.g. GEODSS) have been recently reinforced with the deployment of new systems (e.g. MCAT and Linear DARPA), which are assumed to remain in service up to 2025, providing survey and tracking capability especially in the

32 Source: GAO-15-342SP DEFENSE ACQUISITIONS Assessments of Selected Weapon Programs (https://www.gao.gov/assets/670/668986.pdf#page=133)

GEO region. The ground-based optical systems will be further strengthened by a new space-based optical system (a new SBSS), which will replace the current SBSS in-orbit and this is planned for launch in 2021.

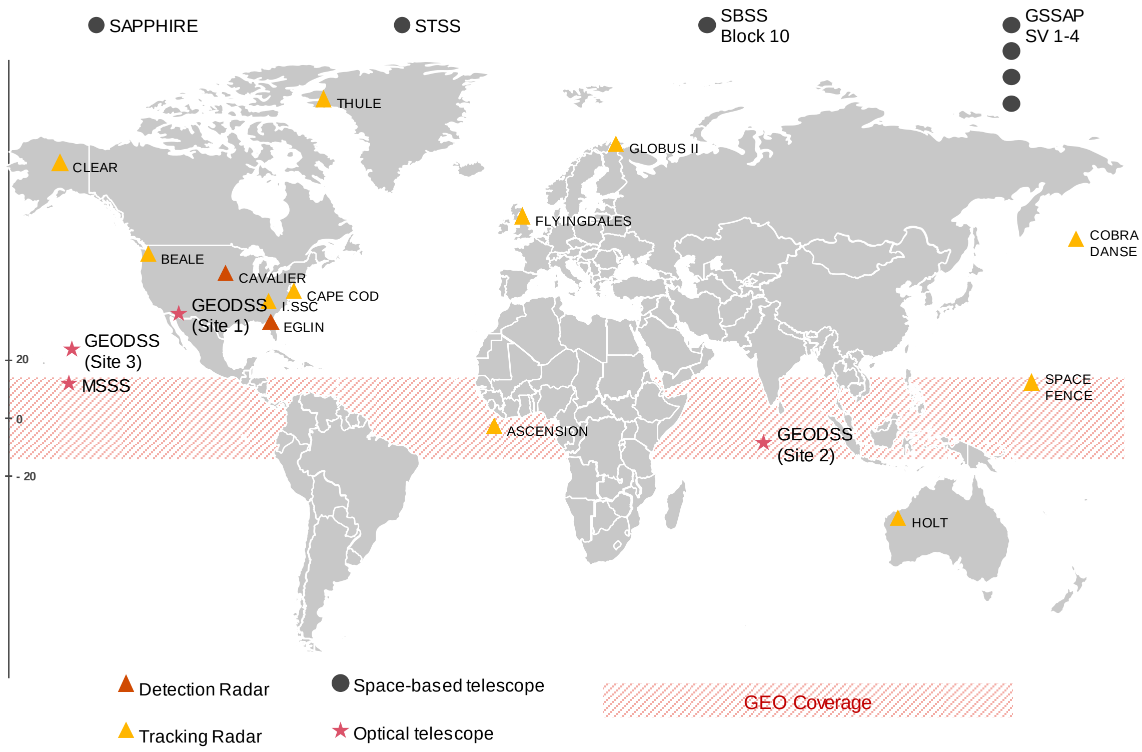
The US SSN Space Surveillance Network is under the responsibility of the **Combined Functional Component Command for Space (CSpoC)**, part of the US Space Force. The catalogue produced by SSN is maintained by the US Department of Defence because originally the SSN has been built to protect military assets. Therefore despite having the most exhaustive database in the world (the US Space catalogue), the CSpoC is theoretically not service-oriented. The CSpoC collects data and information on space awareness and agrees to share (part of) it with the rest of the world free of charge. CSpoC's primary goal is not to deliver public services to other satellite operators, but to protect US Space assets. CSpoC has agreed to let other operators benefit from its data and knowledge, because debris collision is a global issue. Thus even while being an expert in the domain, the CSpoC service is not designed to meet commercial satellite operators' requirements (such as support to avoidance manoeuvers, update of ephemeris, etc.) or to serve any other purposes than US interests. That is why several other initiatives, both private and public, have been launched around the world, as explained below in this section.

The following elements provide the list and geographical distribution of US SST asset:

Table 6: List of US SST sensors

Sensor	Mode	Type
ASCENSION	Tracking	Radar
BEALE	Tracking	Radar
CAPE COD	Tracking	Radar
CAVALIER	Tracking/Detection	Radar
CLEAR	Tracking	Radar
COBRA DANSE	Tracking	Radar
EGLIN	Detection	Radar
FLYINGDALES	Tracking	Radar
GEODSS (Site 1)	Detection	Optical Telescope
GEODSS (Site 2)	Detection	Optical Telescope
GEODSS (Site 3)	Detection	Optical Telescope
GLOBUS II	Imaging/Tracking	Radar
GSSAP SV 1-4	Detection	Space-based telescope
HOLT	Tracking	Radar
I.SSC	Imaging/Tracking	Radar
MSSS	Detection	Optical Telescope
SAPPHIRE	Detection	Space-based telescope
SBSS Block 10	Detection	Space-based telescope
SPACE FENCE	Tracking/Imaging	Radar
STSS	Detection	Space-based telescope
THULE	Tracking	Radar
ASCENSION	Tracking	Radar
BEALE	Tracking	Radar
CAPE COD	Tracking	Radar
CAVALIER	Tracking/Detection	Radar

Figure 12: Distribution of US Space Surveillance Network sensors



Source: US Department of Defense

Russian capabilities

Today, Russia operates the second largest SST/SSA network, the Russian Space Surveillance System (SSS). Indeed, the Russian Federation has decades of technical and operational expertise in all major space-based applications and services including Space Surveillance and tracking (SST). Its SSA/SST network was developed by the Soviet Union in the early 60's.

On the civilian front, Russia has developed the Automated Warning System on Hazardous Situations in Outer Space (ASPOS OKP), with the operations of the system being sub-contracted to the Astronomical Scientific Centre (ASC) by the Russian Space Agency (ROSCOSMOS).In addition to that, the Russian federation also leads the International Scientific Optical Network (ISON), which is an international non-governmental project, and provides freely-accessible SSA data and information for civilian purposes, globally. The network possesses the capability of conducting SST activities in Highly Elliptical Orbits, Geostationary Orbit, and Near-Earth Orbits. Moreover, ISON has the second largest non-government owned network of optical sensors.[33]

Russia's existing capabilities for SSA have been developed under the SSS, ASPOS OKP, and ISON programs. However, little is known about the size and geographical distribution of some of these networks, especially the VKS operated SSS.

The Russian Federations SSS ground network is comprised of electro-optical sensors/phased array radars, Light Detection And Ranging (LIDAR), optical telescopes and radar sensors. In addition to having a vast variety of sensor within their network, recently, the government has been pushing towards expanding this network geographically too. This is evidenced by the proposal made to the Saudi Arabian leadership to place an optical telescope in Saudi Arabia.[34] The Commander of Russian Aerospace Defence Forces in 2017, announced the expansion of their space surveillance network, by adding 10 laser-optical and radio complexes before 2020. In addition to that he also

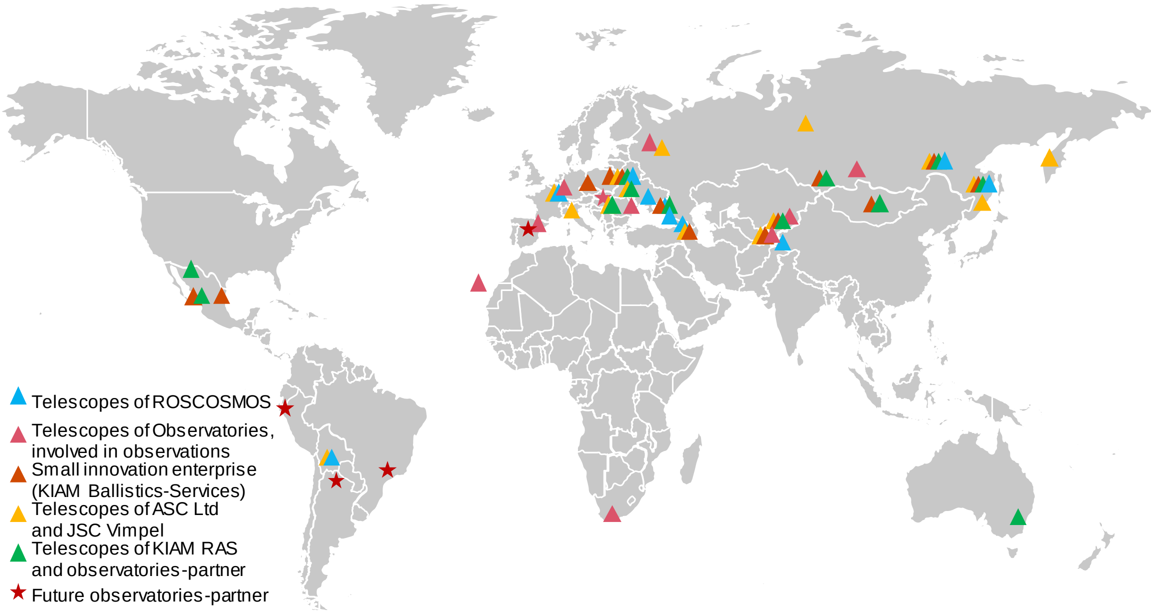
[33] Available at: https://www.ida.org/-/media/feature/publications/g/gl/global-trends-in-space-situational-awareness-ssa-and-space-traffic-management-stm/d-9074.ashx
[34] Available at: https://spacewatch.global/2019/10/saudi-arabia-and-russia-look-to-expand-space-cooperation-including-use-of-ksa-as-possible-satellite-launch-location/

suggested that the Force was constantly working on developing new systems to further enhance their SSS capabilities.[35]

While the Federation has a strong network of ground surveillance systems, it is also developing space-based systems. In 2017, Russia launched an earth observation satellite, which hosted a smaller satellite that detached from the mother spacecraft. This small satellite is a probe that is capable of approaching and imaging other space objects.[36] In addition to that, in 2019, the Russian defence minister announced the successful launch of a satellite that would undertake both earth observation applications and space surveillance applications. However, it is not known if this satellite is a one-off, or a part of a constellation program.

In addition to that the Russian led ISON is collaboratively operating 43 observation facilities, with 100 telescopes in 17 countries. While the KIAM ballistic centre processes the data derived, observed and tracked by ISON and is used for collision risk analysis and space situational analysis.

Figure 13: ISON's Geographical distribution of sensors, 2017



Source: Science & Technology Policy institute, PwC analysis

This ISON network is also constantly expanding both in terms of sensors deployed and the geographical locations covered to maximise visibility in space. Within the 2010 – 2017 timeframe, the network expanded in Europe, Africa, Latin-America, North America, and established its first centre in the Oceania region. Moreover, the Russian ASPOS OKP operated a total of 22 telescopes/ 36 optical modules in 2018 and plans to expand this network to 23 telescopes/ 41 optical modules in the near future. In terms of geographical coverage, the network is expected to deploy its sensor in the continent of Africa.[37] It is quite clear that Russia has enough technical prowess in terms of ground-based and space-based surveillance capabilities, thereby placing them in a strong position to conduct SSA activities.

Chinese capabilities

The Chinese SSA network falls shy of the ones currently being operated by USA and Russia. Both these nations have a strong heritage in operating SSA networks. China on the other hand, has just recently began developing its network. It is estimated that China maintains the following set of capabilities:

[35] Available at: https://www.express.co.uk/news/world/862350/Russia-space-agency-surveillance-system-2020-NASA-space-station
[36] Available at: https://spaceflightnow.com/2019/11/25/russia-launches-space-surveillance-satellite/
[37] Available at: https://www.unoosa.org/documents/pdf/copuos/2018/copuos2018tech05E.pdf

- Two ground-based optical sensors
- Four ships capable of performing SSA
- Four large Phased-Array Radar (LPAR) sites dedicated to identifying missile attacks
- Three telemetry, tracking, and control centres

Although this network is comparatively small it possesses the capability of conducting SSA/SST activities in all Earth orbits. It is furthermore believed that China is expanding this network to further strengthen its counter space capabilities.[38] Additionally, from a data processing standpoint, it is believed that there are some internal capabilities that have been developed China, but are still reliant on conjunction warning provided by the US DoD.

In terms of the APOSOS network, ground-based observation systems are located in four countries, China, Peru, Iran and Pakistan, with the aim to establish a large aperture telescope in all of its member states.

European capabilities

the EU has secured over EUR 350 million for the SST programme, which shall be used for projects carried out in this sector by the members of the Consortium to develop capabilities in terms of assets and competences. These investments will benefit in particular new members of the Consortium which have brought addition telescopes, lasers and radars to EU SST capabilities.

In 2019, the EU SST's capabilities were composed of five surveillance radars, 7 tracking radars, 4 laser stations, and an optical network of 35 telescopes, allowing the exhaustive coverage of all orbital regimes (LEO, MEO, HEO and GEO)[39]. The following table lists and details the set of European capabilities in the field of SST:

Table 7: List of sensors composing the EU SST network (2019)

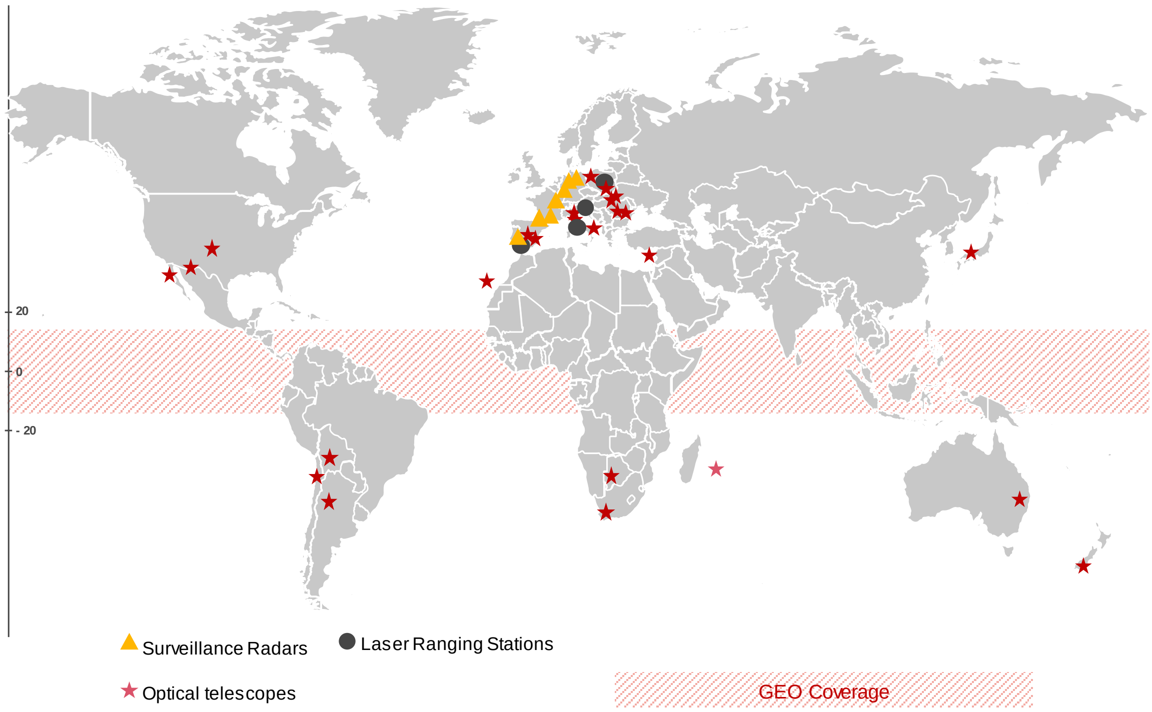
Sensor	Type	Mode	Member State	Location
Borówiec SLR	Laser	Tracking	Poland	Europe
Aniin -San	Telescope	Surveillance	Poland	Asia
Beata	Telescope	Surveillance	Poland	North America
MoonBase	Telescope	Surveillance and tracking	Poland	Africa
PANOPTES 1	Telescope	Surveillance and tracking	Poland	Europe
PANOPTES 3AB (replaced by Idrasil in December 2020)	Telescope	Surveillance and tracking	Poland	Europe
Polonia	Telescope	Surveillance and tracking	Poland	South America
Rantiga	Telescope	Surveillance and tracking	Poland	Europe
Solaris 2	Telescope	Surveillance and tracking	Poland	South African

[38] Available at: https://www.csis.org/analysis/space-threat-assessment-2019
[39] https://www.hou.usra.edu/meetings/orbitaldebris2019/orbital2019paper/pdf/6165.pdf

Solaris 3AB	Telescope	Surveillance and tracking	Poland	
Solaris 4	Telescope	Surveillance and tracking	Poland	South America
PANOPTES Coast	Telescope	Tracking	Poland	Africa
PANOPTES MAM AB	Telescope	Tracking	Poland	Europe
PST-2	Telescope	Tracking	Poland	North America
GRAVES	Radar	Surveillance	France	Europe
SATAM 1	Radar	Tracking	France	Europe
SATAM 2	Radar	Tracking	France	Europe
SATAM 3	Radar	Tracking	France	Europe
TAROT 1	Telescope	Surveillance and tracking	France	South America
TAROT 2	Telescope	Surveillance and tracking	France	Europe
TAROT 3	Telescope	Surveillance and tracking	France	Africa
GESTRA	Radar	Surveillance and tracking	Germany	Europe
TIRA	Radar	Tracking	Germany	Europe
SLR Graz	Laser	Tracking	Germany	Europe
BIRALES	Radar	Surveillance	Italy	Europe
BIRALET	Radar	Tracking	Italy	Europe
MFDR	Radar	Tracking	Italy	Europe
MLRO	Laser	Tracking	Italy	Europe
SPADE	Telescope	Surveillance	Italy	Europe
TFRM	Telescope	Surveillance	Italy	Europe
CAS	Telescope	Tracking	Italy	Europe
Cassini	Telescope	Tracking	Italy	Europe
PdM-MiTe	Telescope	Tracking	Italy	Europe
ROA SLR	Telescope	Surveillance	Portugal	Europe
NEEMO-35	Telescope	Surveillance	Romania	Europe
T04-Berthelot	Telescope	Surveillance and tracking	Romania	Europe
NEEMO-50	Telescope	Tracking	Romania	Europe
T030-AROAC	Telescope	Tracking	Romania	Europe
T030-BitNET	Telescope	Tracking	Romania	Europe
S3TSR	Radar	Surveillance	Spain	Europe
ROA SLR	Laser	Tracking	Spain	Europe
CENTU	Telescope	Surveillance	Spain	Europe

Bootes 3	Telescope	Tracking	Spain	South East Pacific
Bootes 5	Telescope	Tracking	Spain	North America
IAC-80	Telescope	Tracking	Spain	Europe
TJO	Telescope	Tracking	Spain	Europe
Tracker	Telescope	Tracking	Spain	Europe

Figure 14: Mapping of EU SST sensors (2019)



Source: EU SST, PwC analysis

It is key to mention that the integration of Poland, Romania and Portugal into the EU SST consortium has significantly improved Europe's SSA capabilities by enhancing its optical worldwide coverage. As such, Poland provides a set of telescopes located around the globe, in Poland, Argentina, Australia, Chile, RSA and USA, owned by both Polish universities and industrials. Through this contribution, Poland and the Polish Space Agency is able allow to the further develop the domestic capabilities related to observation and situational awareness in space, grow the competences and the competitiveness of the domestic space sector, and increase its role in the current and future EU and ESA programmes, strengthening the position of Poland in the international arena. Benefiting from the EU SST Consortium overall budget, Poland will also establish, develop and explore the national situational awareness system under its the National Space Programme 2019-2021[40].

The ESA SSA Programme

The ESA SSA Programme is being implemented as an optional ESA programme with financial participation by 19 Member States. Funded at a total of approximately EUR 95 Million for the timeframe 2017-2020, it was boosted up to EUR 432 Million for the timeframe 2020-2024 (+354%) following the Space 19+ ESA ministerial in November 2019, highlighting the growing interest from ESA Member States for Safe Space Operations. It is assumed that participating Member States for the timeframe 2017-2020 are likely to subscribe again for the 2020-2024 programme, and will be Austria, France, Sweden, Portugal, Belgium, Germany, Netherlands, Romania, Czech Republic,

40 According to Mr Grzegorz Brona PhD, president of the Polish Space Agency, Polish Space Agency Website.

Greece, Norway, United Kingdom, Denmark, Italy, Poland, Switzerland, Finland, Luxembourg and Spain. The SSA Programmes is structured around three objectives[41]:

- Secure Europe's access to space, protecting the involved economies and strengthening European industry
- Reduce dependency on US derived SSA data and generate in-house value-added products that rival the data received from the US Department of Defence (DoD)
- Build a European capability to monitor the space environment for hazards, both natural and human-made that could impact assets in orbit or populations and infrastructure on the ground

As such, ESA SSA Program places focus on R&D to support and improve domestic SSA goals, and enhance European SSA capabilities, directly supporting the EU's motivation towards being an enabler of SST/SSA and STM services through three priority topics: Space Weather, Near Earth Objects and SST. In particular activities running to 2020 place increased emphasis on developing space weather and NEO services, while research, development and validation activities continue in the domain of space surveillance and tracking.

In addition to its main entities ESRIN, ESTEC, ESAC and ESOC and its own SSA capabilities (the Optical Ground Station in Tenerife, tests telescopes in Spain and Chile), the ESA SSA Programme relies on the collaboration with other European and international organisations, including:

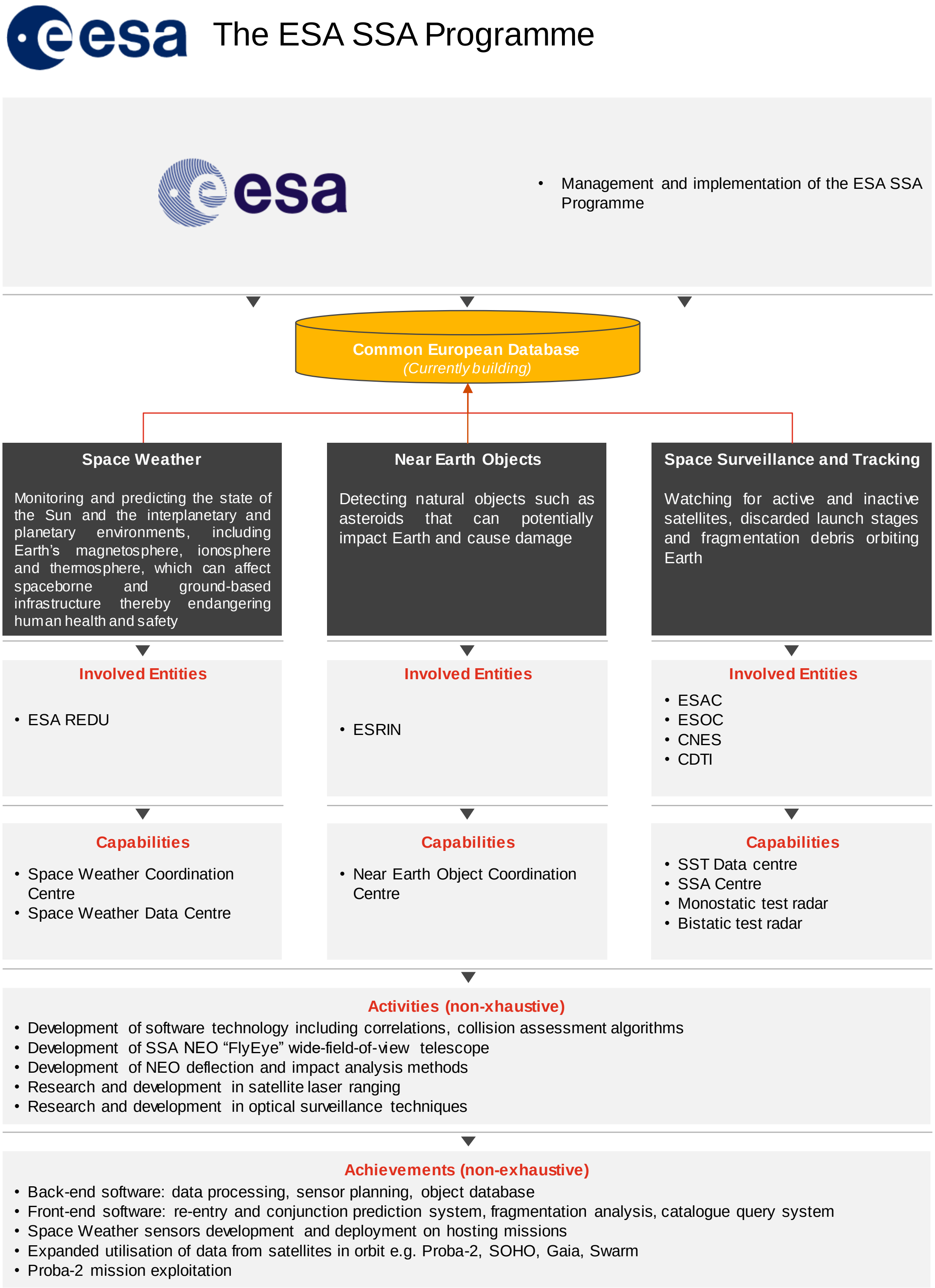
- Space Weather Centres of expertise across Europe
- National radar, laser and optical capabilities for NEO and SST from the ESA MS involved
- EISCAT research radars
- IAC
- COSPAR
- IADC
- UNCOPUOS
- ESO
- USSTRATCOM (signed agreement for SSA data sharing)
- External partners: USA, South Korea, United Nations

In particular and as examples of these collaborations for the SST segment of its SSA programme:

- ESA has a collaboration with the Fraunhofer Institute on the Tracking and Imaging Radar (TIRA) system for tracking and monitoring space objects of diameters down to 2 cm at 1,000 km range
- ESA is operating since 1997 the Optical Ground Station (OGS), part of the Instituto de Astrofísica de Canarias' Teide Observatory. The OGS is used to test laser communication terminals aboard satellites in low and geostationary orbits, as well as for deep-space usage and for precision tracking of space debris. It can detect and track near-GEO objects up to down to 15 cm in size.

41 https://www.esa.int/About_Us/Ministerial_Council_2016/Space_Safety_Space_Traffic_Management_Programmes

Figure 15: Overview of the ESA SSA Programme organization and activities



Source: ESA, PwC analysis

Though it pushed to enhance its capabilities, the ESA SSA programme faces numerous challenges, as partially relying on US Department of Defence for SSA data, and because of its overall limited data processing capabilities and its difficulty to offer plug-and-play data products[42].

Furthermore, ESA faces significant political challenges as it is not identified as a relevant SST operator from a national security perspective of its Member States willing to develop and operate their own independent SSA capabilities to safeguard their national assets. This particularly the case for France which opposed to ESA's operational SSA initiatives, as described further.

Clean Space: an initiative from ESA to mitigate and eventually demonstrate the viability of actively removing debris

Clean Space is an initiative by the European Space Agency, aimed at minimizing the impact and presence of space debris, along the entire lifecycle of space activities. Clean Space is built upon three solutions, namely**:** EcoDesign CleanSat and In-orbit servicing/Active Debris Removal.

EcoDesign consists of involving space environmental awareness and sustainability in the phase of mission design, in order to minimize wastes and inefficiencies that could furtherly pollute the earth and space environment. It includes the development of technologies that are compliant with EcoDesign mission requirements. Related R&D activities include for instance testing of space batteries' resistance to extreme conditions and destruction threats, to better understand how to avoid their uncontrolled dismissal in space.

CleanSat: concerns the process of building space infrastructure and technologies in order to avoid the creation of new debris. It involves designing "for demise" meaning the complete burnup upon re-entry.

In-orbit servicing/Active Debris removal defines the actual removal of existing debris and the demonstration of in orbit servicing. In particular and within this third solution, the e.Deorbit mission, an initiative primarily aiming at taking down a derelict satellite, was recently reconsidered for a wider objective as a new space servicing vehicle to perform a variety of different roles in orbit, including the refuelling, refurbishing or reboosting of satellites already in orbit. Through this mission, ESA is willing to support the development of a more general-purpose Space Servicing Vehicle acting as a demonstrator for the business case of In-Orbit Servicing. To that extent, ESA Clean Space funding was used to mandate industrials to make proposals to remove defunct ESA objects[43].

Following this initiative, the CleaSpace-1 mission will be launched in 2025 as the first ever mission to remove an item of debris from orbit. The mission will be procured as a service contract with a consortium led by ClearSpace, a Swiss start-up, and implemented by an ESA project team. It is expected to use the results and findings of another ESA CleanSpace initiative for Active Debris Removal and In-Orbit Servicing called ADRIOS. However, the extent to which the ClearSpace-1 mission will capitalize on the e.Deorbit mission are unclear.

Other initiatives from the European Commission on Debris mitigation and Active Debris Removal

Through its Research Programme Horizon 2020, the European Commission funded the D3 Project. The D-Orbit Decommissioning Device, (D3) is an independent, smart device based on solid propellant technology optimised for decommissioning manoeuvres, which is installed directly on satellites and/or the initial launcher that propels the satellite into orbit. D3 was designed to ensure traceability of a de-orbited re-entering satellite with the objective to make it fall in a predetermined and unpopulated area. The PROTEC-1-2015 is another project funded by the European Commission aimed at developing and testing concepts and technologies for safe de-orbiting and disposal of space objects.

Following a call for tender for which 12 candidates participated, ClearSpace was selected by ESA to develop and conduct an Active Debris Removal mission by 2025. Such mission is known as ClearSpace-1 and shall aim at demonstrating the set of technologies required to capture and

42 https://www.ida.org/-/media/feature/publications/g/gl/global-trends-in-space-situational-awareness-ssa-and-space-traffic-management-stm/d-9074.ashx
43 https://www.esa.int/Safety_Security/Clean_Space/ESA_s_e.Deorbit_debris_removal_mission_reborn_as_servicing_vehicle

sustainability deorbit a Vega payload adapter from a launch performed in 2013. The contract value of the ClearSpace-1 is estimated to be €86 Million[44]

Based in Japan and initiated in 2013, Astroscale is developing on-orbit missions and services including satellite life extension, in-situ Space Situational Awareness and deorbiting activities for satellite having reached end of life. Astroscale is targeting the demonstration of its technology through a debris removal operation in LEO called End-of-Life Service by Astroscale-demonstration (ELSA-d). The company has raised over $191 Million since the beginning of its activites.

2.7.1 Market Dynamics

The private sector is developing several capabilities in the field of SST, space safety and sustainability, which are materialised through various types of technologies and configurations. Driven by the increased need from all types of satellite operators (public and private) to retain safety and security as a top priority for their spacecraft and associated mission, the market for SSA value added products and services is expected to mature.

Overview of the main private initiatives in the field of SSA

The first private and commercial initiative in the field of SSA was the creation of the Space Data Association (SDA). SDA was created from a joint initiative between prime satellite operators who decide to co-fund a system allowing the sharing of their data and ephemeris. SDA pools together data provided by its members in LEO and GEO and data made available by US Combined Space Operations Center (CSpOC).

The ecosystem of SST services in the US is well developed, with multiple vendors in the service value chain. In Europe, although SST functions are traditionally carried out by public actors and institutions, the private sector is developing SST capabilities at different levels in the three core functions (sensor, processing, and service function) as well as other value-added services (VAS).

The following sections provide an individual description of the main companies that are developing capabilities and provide commercial services in the field of SST, Space safety and sustainability.

AGI (Analytical Graphics, Inc.)

Since its foundation in 1989, AGI delivers software applications and development tools for defence and intelligence missions. The US national security organisations have used AGI's software since 1994. In fact, in 2012 AGI won an order contract from the US Air Force to provide its Space Situational Awareness (SSA) Software Suite to the CSpOC Mission System (JMS) program, which remained a US military-driven system (i.e. military operates the software). This contract positioned AGI as a key contractor to upgrade the Command Space Operations Center. AGI's software suite works with service-oriented architecture (SOA). This type of software has specific characteristics: it has the potential to adapt to growing level of computing processes in a reliable and secure fashion, it ensures database integration (only trustworthy, and authoritative data is stored) and also allows web-based user interactions.

Capitalizing on its experience, AGI has also developed its SSA services based on a network of sensors in leasing under the Commercial Space Operations Center (ComSpOC). The ComSpOC is a more sophisticated service offer, as it is operational since 2014 and it uses a diversified sensor network including optical, Radio Frequency (RF), radar and space-based sensors for LEO and GEO orbit regimes. The network includes traditional sensor sources such as: SSN, SBSS, Fylingdales, Vardo, Sapphire, TIRA, ESTRACK (ESA), ISTRACK (ISRO), EISCAT, Chibolton, among others, and non-traditional sensor sources such as: missile data, hosted payloads, OPIR, satellite operators and telescopes[45]. AGI won two important contracts in 2015, the first one with Boeing to

[44] https://spacenews.com/clearspace-contract-signed/#:~:text=Once%20launched%2C%20the%20ClearSpace%2D1,orbit%20for%20commissioning%20and%20testing.&text=The%2086%20million%20euros%20in,Seville%2C%20Spain%20a%20year%20ago.

45 Source (Available Online): ITU Satellite Communication Symposium May 2017 - The Commercial Space Operations Center (ComSpOC)

track the launch and early orbit operations of two all-electric propulsion satellites, while the second one was a USD $8.4 Million Air Force Contract for a subscription to CompSpOC services[46].

Based on its legacy and knowledge of database management software and software analysis in the field of space situational awareness, AGI is expected to take a prominent role in the ecosystem of US actors involved in Space Traffic Management within the next five years.

ExoAnalytics Solutions

ExoAnalytic Solutions was founded in 2008 to provide traditional defence contractor services to the US federal government and commercial customers. Today, ExoAnalytic Solutions' ESpOC remotely commands and controls more than 25 observatories and 200 telescopes in different orbital regimes (GEO, HEO, MEO) to feed "SpaceFront", a datawarehouse and analytics engine of space objects with highly accurate real-time tracking data. This data repository allows efficient data (and metadata) collection, processing, correlation and analysis which are necessary to improve advanced algorithms and reduce uncertainty. Moreover, SpaceFront also stores a space object's historical long-term behaviour including: frequency of manoeuvre, maintenance of orbital position, and seasonal attitude adjustment. These capabilities allow ExoAnalytic Solutions to provide commercial SSA services such as launch monitoring, conjunction analysis, warning and secondary screening, anomaly detection and resolution, among other customized services for satellite operators.

The ExoAnalytic Global Telescope Network is positioned to support Space Traffic Management activities, as it has demonstrated over the past its capacity to provide a large amount of SSA-related data to different space customers, and plans to increase its capabilities to keep pace with the evolution of needs related to an STM system.

LeoLabs

Commercial companies in the US not only offer their services for MEO and GEO regimes, but also to LEO. The venture-funded company LeoLabs Inc. provides responsive tracking services in LEO to detect, map and help avoid collisions. LeoLabs was founded in 2016 in California to provide services such as rapid orbit determination, operational support in early stages, and on-going orbit awareness to satellite operators, satellite management services companies and government and space agencies with a global radar network and data services platform. The company is building services focusing on ventures with small-satellites networks, and short tourist flights (e.g. Virgin Galactic). In 2017, the start-up raised a $4 million seed investment from Horizon Ventures, SRI International and Airbus Ventures, and is developing its tracking radar network that aims at being able to track all objects larger than 2cm (around 200,000 objects).

NorthStar Earth and Space

New commercial service providers also include the Canadian commercial venture NorthStar, which aims to provide services in space monitoring and risk mitigation in LEO and GEO such as Launch & Re-entry Assessment, Space Object Assessment, Space Debris Monitoring, Collision Risk Management and Space Traffic Management. NorthStar system will have activities in the three SST functions with a planned constellation of 40 Earth Observation (EO) satellites with SSA sensors in LEO, data processing functions and a VAS platform with cloud-based data and services[47]. These capabilities represent a total funding of 83 Canadian dollars[48].

In December 2019, the Luxembourg Government and NorthStar signed a Letter of Intent towards the launch and development of a Centre of Excellence for Clean Space in Luxembourg. Based in Luxembourg, this centre shall be operated by NorthStar to provide efficient and precise SSA and STM services. In addition, the Centre of Excellence for Clean Space shall foster cooperation initiatives between the ecosystem of players evolving in the space and data analytics sectors in Luxembourg.

46 Source: Spacenews, AGI wins USD 8.4 Million Air Force contract for orbital data.
47 RHEA Group, Northstar: A Canadian Commercial Venture Opening New Markets For Geospatial Services, November, 22 2016 from URL <https://www.rheagroup.com/news/northstar-canadian-venture-geospatial-services>
48 SpaceNews https://spacenews.com/leo-startup-raises-39-5-million-for-constellation-to-watch-earth-and-space/

Schafer Corporation

In 2016, the US-based technology services corporation Schafer announced the creation of a new business unit dedicated to Commercial Space Situational Awareness (CSSA). With more than 85 sensors[49], the company plans to monitor LEO and GEO regimes to provide accurate and on-time services such as high accurate position, orbit predictions and actuarial data for insurance claims.

ArianeGroup

ArianeGroup's GEOTracker is based on a network of ground-based telescopes located in France, Australia, Spain and Chile, monitoring the MEO and GEO orbital regimes with the capacity to observe objects of up to 50 cm in size. GEOTracker's catalogue was built-up autonomously in order to fully cover the geosynchronous ring, and it only uses the US catalogue for the object's nomenclature and identification. Since 2017, ArianeGroup's GEOTracker supports the French Space Command in the surveillance of space systems by providing optical observation data allowing the identification of any potential threat in the MEO and GEO regimes. In September 2018, the GEOTracker network allowed the identification of the Russian spy satellite Luch-Olymp, which was attempting to eavesdrop and intercept communications from Athena-Fidus military satellite[50].

Sybilla Technologies

Sybilla Technologies is a Polish company which has developed IT solutions and capabilities in the area of astronomy and astrophysics. The company is developing turn-key robotic solutions supporting astronomical observation purposes. Sybilla technologies has also developed specific expertise in the modelling and tracking of space objects and space debris.

6ROADS

6ROADS is a Polish company based in Cracow which has developed a network of six optical sensors spread globally in Poland, Spain, Italy and Chile. 6ROADS has developed a surveillance system allowing the detection of new space objects and/or the identification which may have been lost of tracking records. The company has fostered cooperation with the Academia and Scientifics sectors to develop its SST solutions.

Cilium Engineering

Found in 2014, Cilium Engineering is a Polish start-up company which develops astronomical equipment and environment monitoring equipment. Cilium Engineering has developed a module system allowing the remote operations of observatories called 2πSky. This solution allows observation centers to be autonomous.

The following figure provides an overview of the main private and commercial service providers in the field of SSA and most specifically in SST:

49 Parabolic Arc, Schafer Corporation Forms Commercial Space Situational Awareness Unit, May 29, 2016 from URL <http://www.parabolicarc.com/2016/05/29/schafer-corporation-forms-commercial-space-situational-awareness-unit/>
50 Source : PwC.

Figure 16: List of main private and commercial service providers in the field of SSA

Data gathering	• SDA • ExoAnalytic Solutions • LeoLabs • Share My Space	• Zodiac Aerospace • ArianeGroup • 6ROADS • Cilium Engineering
Data processing and storage	• AGI • Applied Analytics Solutions • Omitron • Solers • Share My Space • ExoAnalytic	Solutions • Schafer • A.I. Solutions • Lockheed Martin • LeoLabs • Sybilla Technologies
Data analysis	• AGI • Applied Analytics Solutions • Omitron • Solers • Schafer • A.I. Solutions	• Share My Space • Lockheed Martin • North Star • ExoAnalytic Solutions • Applied Defense Solutions, Inc.
Service provision	• AGI • Lockheed Martin • Schafer • North Star • LeoLabs	• ExoAnalytic Solutions • Applied Defense Solutions, Inc. • Share MySpace

A nascent market with specific needs and requirements that are still to be formulated and stated

Service providers are positioning themselves on a nascent market, with users and customers who are still defining their needs. Indeed, it is difficult for users to distinguish and quantify for now the real value between free services, as they are provided today, and commercial paying services. Indeed, users have been used to collect free data provided by national and cooperation based SSA networks. So far, the usage of this data has satisfied users as an extremely low number of collisions have occurred in the past years. Therefore, it is difficult for users to grasp the reasons why they should be for additional services. In fact, users only require tailored services that typically consist of providing information of the objects that could cross a given area around the spacecraft under scrutiny.

Service providers have difficulties in signing large contracts that would aim at providing a global coverage and observation of a given orbital region rather than a specific focus on one or several spacecraft. Given the important costs required to develop surveillance and tracking tools that would support theses services, commercial service providers need an anchor contract with a public or private customer to develop and demonstrate the real added value of these paying services in comparison with free data. Therefore, the short-term priority for service providers is to ensure a sustainable volume of activity that can generate enough cash to sustain the network and infrastructure that they have developed so far to provide their services. However, this might change with the deployment of mega constellation satellites, which may raise awareness among users on the value of commercial services that observe a large portion of space.

2.7.2 Regulatory Environment

For the past decades, several actions have been initiated at European and International level for the implementation of Space Surveillance and Tracking activities, with the current concept of SST expected to evolve in the more complex concept of Space Traffic Management. How this will be implemented is still unknown, considering that major international stakeholders (E.g. US Government, the European Union, the Russian Federation, China) have, so far, pushed forward different and conflicting implementation concepts or have not yet clarified their position. Such legal gap that makes it difficult to require all space actors to strictly follow debris mitigation measures, and to collect proof that satellite owners and operators have intentionally tried to circumvent these measures.

Space laws and regulations are facing an increasing need for adaptation to new challenges brought by new space applications

Space laws and regulations have been under development since the early 1960s. The development of the legal framework governing the exploration and use of outer space can be timed in three phases.

During the first phase between the early 1960s and the early 1980s, the backbone of international space law has been set by the five multilateral treaties developed under the auspices of the UN, of which the most prominent is the Outer Space Treaty.

During the second phase between the early 1980s and the mid of the 1990s, certain (non-binding) UN GA Resolutions on particular human activities in outer space such as direct broadcasting, remote sensing, and the use of nuclear power sources have been adopted.

During the third phase which started in the mid of the 1990s and which is still ongoing, existing principles/concepts entailed in the UN space treaties are further specified and/or interpreted through UN GA Resolutions or other non-binding instruments such as technical guidelines.

Overall, we are witnessing a growing reluctance of States to find international consensus. At the same time, new problems and questions raised by the development of NewSpace activities call for legal and regulatory activities, in particular in the area of STM. Even though early ideas about the need to develop “traffic rules for outer space” were already put forth in the 1980s, as to now, the legal and regulatory framework does not conceptualise a fully-fledged traffic management system.

In a context where multilateral initiatives have slowed-down, national legal and regulatory initiatives are, in the view of some States, more and more at the forefront of the progressive development of space law. National laws are nowadays not only used as a tool to implement what was agreed at the international level, but, for some States, are also considered as a tool to foster the progressive development of international rules. National laws and regulations on the use of space resources adopted by the US and Luxembourg provide for evidence on such a growing unilateralism. In the area of STM, national initiatives by the US driven by Space Policy Directive-3 on the US National Space Traffic Management Policy raised strong concerns that the US aims to promote national standards as de facto internationally applicable standards filling the current regulatory vacuum.

The absence of enforceable regulations

It appears that the current regulatory framework around space safety remains relatively timid. At the international level, legally binding obligations on the protection of the outer space environment are quite vague. Article IX of the 1967 Outer Space Treaty stipulates that states should take appropriate measures to avoid the harmful contamination of outer space without specifying these measures. International guidelines on the matter such as the IADC space debris mitigation guidelines are not binding. These guidelines are often transformed into (binding) national laws. However, the level of implementation differs among jurisdictions. Further, it is difficult to enforce such guidelines, even if they are transformed into (binding) national laws. With current global observation capabilities, it is difficult to collect proof that satellite owners and operators have intentionally tried to circumvent space debris mitigation measures. Should certain trends, such as the deployment of mega-constellations and small-satellites, be confirmed, then there will be a strong need to implement legally-binding, uniform and enforceable regulations for Space Traffic Management.

Standards developed in the SSA/SST field of activities

The three domains of SSA (SST, SWE and NEO) share similar gaps in terms of standardization. The different systems developed by the ecosystem of stakeholders of SSA need more efficient and streamlined interfaces. The formatting of data is not always compatible for instance.

In the SST domain, the CCSDS (Consultative Committee for Space Data Systems) has a working group (navigation working group) that is focused on the development of technical flight dynamics standards (orbit/trajectory, attitude, tracking, manoeuvre, pointing, orbital events, conjunction assessment, etc.). This includes as well SST-relevant standards for the formatting of CDMs (Conjunction Data Messages), ODMs (Orbit Data Messages), and TDMs (Tracking Data Messages). The development of standards for the formatting of re-entry data messages is on-going, and the project to develop standards for formatting and processing of fragmentation data message is in the pipeline.

Standards issued by CCSDS are automatically transferred into ISO standards, whereas CEN/CENELEC European Norms are not. Therefore, in order to avoid duplicating the efforts of CCSDS, Working Group 2 (SSA Monitoring), focuses on the adoption of CCSDS standards where possible but also on identifying and developing standards that have not been developed at international level but are considered necessary for SSA activities.

Regarding the two other SSA domains, SWE and NEO, no standardisation efforts are pursued by CCSDS. Therefore, the JTC5 and WG2 have a larger scope to cover. For NEO, standardisation activities are just starting. Many technical interfaces are not standardised, which may imply difficulties and issues to harmonise their usage. Draft standards for the formatting of telescope messages are being developed. In addition, the WG2 is developing a glossary of terms for both SST and NEO. For SWE, products have very different natures, and a well-defined set of SWE metrics and scales is currently missing.

Standards have a crucial role to play for SSA activities. Especially for NEO and SWE, the organisations and industry will benefit from standards to build a European network for these activities. Some standards for SSA elements are already existing, with, as seen above, heterogeneous level of maturity for standards in the three domains composing SSA. There is a need to develop standards that will enable the harmonisation of different SSA systems and strongly support the development of a system-of-systems of SSA activities.

With lowered barriers to entries partly driving the emergence of the New Space community, the overall population of satellites is expected to significantly increase during the next decade. Such increase of spacecraft in-orbit will require the implementation of an effective Space Traffic Management system in order to ensure a sustainable and safe use of space infrastructures. Every day, more than 2000 tracked satellites pass each other within a close range of 5km . As a mitigation measure, the IADC recommends satellite manufacturers and operators to plan for decommissioned satellites a de-orbiting procedure within 25 years of their final use. While objects below 650km will be brought down within 25 years and burn up on re-entry because of the atmospheric drag, all other spacecraft above that threshold altitude will require an active mechanism to be brought to a lower orbit and reach re-entry. However, the instauration of mitigation measures based on a 25 year timeframe might not be enough to lower the risks of collision and debris production, even when considering the thorough application of the production recommendation mentioned above. The LEO orbit could be managed as the air traffic is, with the attribution – by institutional bodies – of “space corridors” to either private companies and/or institutional bodies and space agencies. A sustainable LEO regime cannot be maintained just with the 25 years de-orbiting guideline. In that regard, constellation operators and manufacturers should be driven or incentivised to introduce sustainability in their business models under penalty of the Kessler-Syndrome.

Future developments in the regulation of SSA and space safety activities will pursue the trend towards a more secure use of outer space by the growing number of satellite operators, especially in the field of mega-constellations. It is foreseeable that guidelines will remain a strong type of soft regulation in the coming years, but we also expect that should a major in-orbit incident happen in the future we might observe a switch to more stringent regulations of in-orbit activities where operators will be forced to follow stricter rules in order to avoid any potential collision with increased attention given to liability of operators. In addition, we foresee that new space exploration missions that involve attempts to land on celestial bodies like asteroids, or test new technologies that require the smashing or crushing of celestial bodies will be heavily scrutinized by regulations in the future in order to ensure that all the consequences of such activities that will be mostly space research will not create any major risk for planet Earth. Such risks could entail for instance displacement of orbits of celestial bodies, or creation of potentially harmful debris resulting from the experimentations performed in outer space.

3Concept Identification

This section aims at providing POLSA with an understanding of the scope of elements and activities that are required and that must be considered for the development of concept for the development of the Polish space sector in one of the areas of the future: lunar exploration. The section introduces the concept and details the scope of elements which must be considered, and provides recommendations on the potential strategic positioning that Poland could adopt in order to embrace the opportunities related to lunar exploration.

3.1 Concept presentation

The concept identified by PwC which could be examined by Poland for the development of a concept for the development of the Polish sector in promising future space activities is Lunar exploration and mining.

Overview of scope of activities and associated challenges

Lunar exploration encompasses a set of activities which can be organised under several segments. The following figure provides an overview of these segments:

Figure 17: Scope of activities composing Lunar exploration

Construction	The construction encompasses all infrastructure and facilities needed to be built to support the other segment. There are two main activities identified: processing and supply.
Mining	Mining encompasses the extraction of resources that are key to support all the segments.
Agriculture	Agriculture on the surface of the Moon is key to produce food and sustain life. Growing crops on the Moon can be done using "biosphere" cylinders and greenhouses.
Sustain life	Sustaining life includes all elements enabling humans to survive on the Moon surface: habitats to live, water for drinking and breathing, N2 and 02 for breathing, as well as food.
Transit	Transiting includes all activities enabling mobility on the surface of the Moon using lunar vehicles.
Medicine	In order to ensure astronauts health condition, medicine on the surface of the Moon can be considered, with two aspects: health services (pills prescription, clinics, health checks, etc.), and training centres (e.g. treadmills, etc.).
Experiments	Humans on the Moon are expected to dedicate 1/3 of their time to experiments. To do so, appropriate infrastructure such as laboratories is required.
Energy	In order to provide enough energy to sustain the different activities on the Moon, producing and storing energy is key.
Robotics	Robotics will be key to support humans in their activities on a daily basis, may in be for mining, construction, but also with experiments.
Communications	On-Moon Communications enable to connect all humans and objects on the Moon together, using communications systems in situ but also in orbit (e.g. Pathfinder).

These activities come with several challenges which must be considered when envisioning and planning Lunar exploration activities. Mining encompasses the extraction of resources that are key to support the development of human presence on the moon. The most important resource to extract being water, other resources such as regolith and minerals can be extracted to support other functions and perspectives. Water is required to sustain life, ensure transit between Earth and the Moon, operate Greenhouse module, etc. In order to support Lunar mining activities and other functions on the Moon, robotics capabilities are also required. Robotics capabilities would allow drilling activities on the lunar crust and regolith, but appear challenging in the Lunar environment. Conventional drilling techniques utilized on Earth are difficult to apply in space, mainly because of their prohibitive requirements in the mass, volume, and power of the equipment, their common reliance on gravity, and on the continuous circulation of drilling fluids. Drilling primarily consists of two processes: breaking the formation in pieces and cuttings, and removing the drilled cuttings. The greatest constraints to space drilling that have to be taken into account in the drill design are:

- The extreme environmental conditions such as temperature, dust, and pressure
- The light-time communications delay (which necessitates highly autonomous systems)
- The mission and science constraints, including (but not limited to) the mass and power budgets, along with the types of drilled samples needed for scientific analysis

Timeline

As introduced in the State of Play analysis, in the section focusing on the Space Exploration segment, Space exploration, and lunar exploration, follow a five-steps approach:

1. Rocket Refuelling
2. Life support
3. Infrastructure
4. Equipment
5. Transportation of resources back to Earth

The deployment and execution of these activities and milestones would be expected to span over a timeline of 20 years.

3.2 Recommendation on potential strategic positioning for Poland

This section aims at providing POLSA with the set of criteria and good practices to take into consideration when examining the possibilities for the Polish space sector to develop activities in the areas related to Lunar exploration and mining.

The main aspects to consider when defining the strategic positioning of Poland in the field of Lunar exploration can be nested under four main areas:

1. Political
2. Economic
3. Technological
4. Legal

The following paragraphs provide an understanding of these different areas and highlight the potential enables which could allow Poland to position itself in Lunar exploration activities.

Political Area

The participation to a Lunar exploration mission is conditioned by the political and social incentive and will. Indeed, such type of endeavour implies public spending that needs to be clearly justified and for which positive outcomes and benefits must be properly exposed to decision makers and taxpayers. Therefore, should Poland decide to carry out and participate to Lunar exploration activities, it is recommended that POLSA engages with the Public and Decision Makers to communicate and demonstrate the several impacts related to a potential Lunar programme. These impacts entail the fostering and enhancement of Poland's ecosystem in advanced technologies, leading to economic growth and job creation. Strategic impacts would also be triggered by such endeavour as Poland would strengthen its position and presence in the Global Space community.

As examples being carried out by other Space nations, the US have reinforced its focus on the Moon, in particular through a more consensual vision within the US congress on supporting lunar exploration activities and the Artemis programme. A high degree of involvement from countries such as Australia, Luxembourg, Canada and Japan are being observed and are expected to accelerate Lunar activities. In Japan for instance, the “Space Basic Plan” aims to undertake lunar resource exploration programs, and activate its private sector (space and non-space) in such activities. On top of these different initiatives being led at global level, the strong media impact of the return of manned missions to the surface of the Moon could stimulate the public sentiment.

It would be unrealistic to imagine that Poland would take the decision to independently lead a Lunar mission. Major Space faring nations have recognised the need for international cooperation to carry out such achievement. Therefore, it is recommended that Poland explore potential partnering schemes and agreements should it confirm its willingness to participate to a Lunar mission. The international community is pooling its capabilities and resources to cover the needs and requirements involved in Lunar activities. Japan and USA signed a Joint Exploration Declaration of Intent for space corporation - cooperation on Artemis program, gateway and lunar surface exploration. The success of the Luna27 mission could lead to a fruitful co-operative partnership between Europe and Russia in the future. Canada is fostering relations with other space agencies notably ESA and NASA, and also signed the US Agreement on resource mining on the Moon, therefore highlighting its political will of exploring the Moon. There are however rival pairs (USA vs. Russia, and USA vs. China), which are most likely to exclude cooperation schemes on lunar exploration missions.

Economic Area

In the Economic area, Poland should identify the network of players who could support the deployment of a Lunar exploration mission. These players include national players, but also international players who could be attracted by the idea of developing their presence in Poland. Non-space companies should also be identified and involved as they could allow spin-ins for Lunar activities and lead to synergies between Polish companies.

Large space companies are moving down the value chain to become Space Resource Utilisation operators. The successful extraction of resources on the moon are expected to persuade large space companies to become SRU operators. As an example, Space X could develop its own infrastructure on the Moon to facilitate its missions to Mars, and as such also become a space mining operator. Poland should consider potential partnerships with Large Private Space companies and encourage partnerships between them and national companies who could act as sub-providers. This would increase Poland’s network in the field of Space Resource Utilisation and prepare the ecosystem of Polish actors to future activities in this field.

The development of Space Resource Utilisation activities are leading to ani increase in demand and funding from terrestrial industries (mining, O&G, automotive, robotics etc.). Mining industries in Australia, Europe and South America have initiated studies for lunar mining. The Japanese entity, Frontier Business Study Group (over 20 member companies), has indicated its participation in lunar construction and mining. The automotive industry has also initiated projects for R&D and business concept of lunar hydrogen infrastructure. As an example, Toyota has already attracted nearly 100 companies to take part in its lunar rover project. Poland could replicate these examples in order to foster synergies between the space and non-space national sectors, which would be expected to lead to economic growth.

Technological Area

From the technological perspective, the main drivers are the successful and timely developments of the relevant exploration and Space Resource Utilisation equipment. Should Poland decide to participate to a Lunar exploration mission, it will be key to identify the set of enabling technologies and equipment allowing the mission under scrutiny to be successfully carried out.

There are three essential technological areas that condition the successful deployment of Lunar mission:

- Access to transportation technologies
- Guaranteed safety and reliability
- High TRL SRU concepts

The availability of cost-effective launch systems with the capability of transporting several tons to the lunar orbit and/or surface is essential. Cost effectiveness solutions today imply the development of reusable capabilities for both the launch system and the lander system. SLS (USA), Starship (USA), H3 Heavy (Japan), Long March 9 are launchers that are already being developed to facilitate cost effective lunar exploration activities. A vast majority of them are expected to enter the market by 2030’s with the exception of SLS which is expected to be operational as soon as 2021.

The second essential technological area is the development of reliable systems that can land and sustain on the Moon. As the intensity of small robotic flight increases and private companies get grow their capabilities and experience, it is likely that the reliability of their systems would also increase. Chandrayaan-2, and Beresheet are recent examples of recent soft-landing mishaps.

The third essential technological area is high TRL for SRU technologies (drilling, refinement, extraction, etc.), and also technologies that support the development of a sustainable lunar presence. These developments are largely dependent on the progress made in prospecting activities on the surface on the Moon. NASA has awarded contracts to further SRU technology development goals. One such example of this is the $10M contract provided to Blue Origin to design and develop a ground-based demonstration of hydrogen and oxygen liquification and storage. ESA is developing SRU technologies that enable resource prospection (ISRU Phase 1 payloads) or production of water (e.g. end-to-end demonstrator). Space Food Sphere in Japan is conducting research and development for the production of food in the lunar environment. Another essential technological area involve concepts supporting the development of prospection capabilities that provide high-resolution mapping of resource distribution, geological features, environmental data.

Legal Area

Before initiating activities in the field of Lunar mining and Space Resource Utilisation, Poland should ensure that these activities take place based on a recognised and approved legal and regulatory framework.

The US and Luxembourg are developing their own national laws, that allow these nations to utilise space resources. The US is also developing the Artemis accord which shall take the shape of a bi-lateral agreement between the US and nations supporting the Artemis missions. A middle eastern country is also developing regulations and procedures to facilitate SRU. According to media leaks, Japan is about create a legislation framing space mining led by ruling party in Japan. The Hague International Space Resources Governance Working Group adopted the Building Blocks for the Development of an International Framework on Space Resource Activities.

Should Poland decide to plan the development of SRU activities, it should develop its regulatory framework in the field of Space Resource utilisation and examine in detail the regulatory framework that are being developed by third countries.

4 Identification and assessment of priorities and opportunities for Poland

This section identifies and analyses the potentials opportunities that could be pursued by Poland within a context suggesting the development of Space Safety initiatives and associated opportunities.

Four main priorities have been identified and are highlighted in the following sections.

Figure 18: Identified priorities

Priority 1	Support and enhance the positioning of Polish Space companies in the field of Space Sustainability
Priority 2	Enhance Poland's positioning in the EU and reduce dependency on third countries
Priority 3	Consolidate Poland’s legal framework in the field of space safety and space resource utilization
Priority 4	Increase awareness on space sustainability

4.1 Priority 1: Support and enhance the positioning of Polish Space companies

The development of space activities, comprising the deployment of large constellation of satellites is leading to a steep increase of space traffic and raising concerns on the issue of space sustainability. The space community is acknowledging the need and priority to encourage sustainable space activities, driving priorities for the development and enhancement of capabilities dedicated to the observation, tracking and monitoring of space objects, and highlighting the relevance of in-orbit servicing and active debris removal operations. Several technological, economic, and strategic opportunities are nested within the challenges posed by space sustainability.

Space Sustainability activities reveal several opportunities for Polish space companies and imply the potential growth and development of their set capabilities, network, along with the expansion their commercial activities at national and global level. The Polish ecosystem of entities and companies involved in the space sector disposes of capabilities which present a strong potential to unlock new opportunities in the field of Space Sustainability. POLSA could act to leverage on the potential of the Polish ecosystem of space companies and entities to reach these opportunities. The successful development of Polish activities in the filed of Space Sustainability would be expected to enhance the competitiveness of national space companies.

Europe has extended and enhanced its capabilities for the observation of space objects with the entry of Poland, Portugal and Romania into the EU SST Consortium and the deployment of new sensors space object observation capabilities such as the GESTRA surveillance radar which became operational in 2019. However, the maintenance and development of European space observation capabilities is still a long way from matching US capabilities. Innovative space objects observation concepts, such as space-borne sensors, could be explored and brought to development in order to enhance Polish and European observation capabilities. Poland may consider the examination of such as concept.

The number of Conjunction Data Messages and alarms notifying of a potential collision of a spacecraft with a secondary object has been surging during the last couple of years. Based on information from the Space Data Center and data from SOCRATES, a typical spacecraft positioned in LEO would come within 1km of a secondary object 2000 times per year on average. In 2020, this figure doubled. This can be explained by two main drivers. First, the number of space objects in LEO is increasing due to the deployment of mega-constellation programmes such as Starlink (Approximately 7000 satellites between 335 and 345km altitude), Kepler (140 satellites at an altitude of approximately 575km) and other small satellites. Secondly, observation means to track, and catalogue space objects have increased their capabilities. The US Space Fence can detect objects smaller than 10cm, which was unprecedented until then, de facto significantly increasing the volume of the catalogue of observed space objects. These factors drive the need to dispose of efficient data processing and analytical capabilities, which would tighten the ability to measure the potential collision risk and lead to a reduction of potential collisions warnings. Capabilities in the field of Big Data and Artificial Intelligence are expected to be required to achieve the reduction of the number of false alarms for potential collisions between space objects. Spacecraft operators would have an incentive to have access to more accurate information prior to the decision making regarding an orbital manoeuvre. Therefore, Poland could encourage its national companies to develop solutions in this area.

The space environment contains a significant amount of debris, which could be removed in order to preserve the sustainability of space. According to ESA's space environment statistics, orbital regimes contain approximately 34000 objects greater than 10 cm, 900000 objects between 1 cm to 10 cm, and 128 million objects between 1 mm to 1 cm[51]. the removal of large and non-functional objects would be expected to limit the increase of smaller objects, as large objects tend to dismantle and dislocate into multiple smaller objects with time and/or following a collision with other non-functional space objects. Several initiatives are being developed to consolidate and demonstrate an efficient active debris concept. Poland could encourage national companies with experience in robotics and familiar with active debris removal concepts to bolster their capabilities and favour national networking and synergies in order to achieve a national active debris removal solution.

Timeline and milestones

When considering the timeline in which these priorities may be carried out by the Polish Space Agency and the ecosystem of Polish space players, proposed milestones are set on the short, medium and long term.

On the short term, it is suggested that Poland continues with the bolstering of it's existing sensors capabilities. The accession of Poland as a Member State of the EU SST Consortium allows Europe to benefit from an important network of optical sensors and positions Poland as a key player in the field of European SSA. Such positioning should be further developed through the streamlining of operational activities related to the network of Polish sensors, and the harmonisation of data collection and distribution processes with the rest of the EU SST consortium members. This would allow existing Polish entities participating to EU SST activities to mature and strengthen their capabilities and allow the potential arrival of new Polish entrants bringing additional sensor capabilities. In addition, Poland should prioritise the development of data processing and analysis related to space objects. This specific area is expected to be

[51] https://sdup.esoc.esa.int/discosweb/statistics/

subject to important demand in the coming years with the increase of data driven by the large volume of space objects and the enhancement of capabilities to observe them.

On the medium term, priorities should be focused on the support to entities developing concepts in the fields of robotics, active debris removal and in-orbit servicing. Demand for such type of activities is still maturing, and a sustainable business model for these activities is still to be confirmed but should be defined within the next three to five years with the confirmation of demand.

On the long term, priorities could be set on the development of specific expertise and capabilities for space resource utilisation activities. These would be built on the heritage developed and consolidated by companies having developed concepts in robotics on the medium term for in-orbit concepts (active debris removal and in-orbit servicing).

4.2 Priority 2: Enhance Poland's positioning in the EU and reduce dependency on third countries

Space situational awareness is of strategic importance for continued use of an increasingly crowded space. Dependence on foreign assets for SSA leads to risks from lack of control over an essential capability. As a new member of the EU SST Consortium, Poland is enhancing its position within the EU by pooling a network of valuable sensors. In return, Poland is given access to SST data produced by the other EU SST consortium members. Poland also has a bilateral agreement with the US SSN, which grants Poland with access to US data. These sharing agreements are essential components to Poland’s strategy and must be consolidated and further expanded in the future to bolster Poland’s positioning in the field of Space Sustainability.

The enhancement of Poland’s positioning in the EU and the reduction of the country’s dependency on third countries would be materialised by the consolidation and expansion of Poland’s observation capabilities. Poland disposes of a large network of telescope located in strategic geographical areas and providing an exhaustive coverage of the Geostationary arc. Poland could enhance these observation capabilities by developing novel sensors which are not provided by other EU SST Consortium members. These novel solutions could be, as an example, in-situ and space-based sensors providing data that would confirm and complement data collected from ground-based sensors. Poland could also develop and offer capabilities in other segments than data collection, and examine possibilities in the fields of data processing, analysis and distribution. As expressed in the state of play analysis, the main challenge in the field of Space Sustainability is the ability to rapidly process and analysis data related to potential collisions and other risks. Currently, Europe still needs to enhance its capabilities in order to fully and rapidly process and examine the large volumes of data. Poland could play a role in this area by developing processing and analysis capabilities based on innovative solutions such as AI and Big Data. Such innovative positioning would bolster Poland’s positioning at both EU and Global level.

This initiative would be expected to lead to two main benefits. Firstly, an expanded access to SST data would allow Poland to safely deploy and control its future spacecraft and space missions. Through data sharing schemes, enabled by Poland’s contribution in the provision of SST data, Poland would benefit from reliable data sets and enjoy a safe space environment for its operations. Secondly, by sharing data with EU Member States and third parties, Poland enhances its strategic positioning, using its observation capabilities as a bartering tool.

Timeline and milestones

In terms of timeline and milestones, short terms actions for Poland would be to continue existing sharing agreements with third parties, while identifying the areas in which data is lacking and could be completed by future Polish capabilities whenever possible. Once gaps in the field of SST will be fully identified, Poland could develop relevant gap fillers the medium term, Poland should further leverage on its existing sensor capabilities and processing capabilities to open new partnerships with third parties.

4.3 Priority 3: Consolidate Poland's legal framework in the field of space safety and space resource utilization

Developing a legal framework dedicated to space activities is essential for the future advancement of space projects in Poland. A proper legal framework that regulates space activities is helpful in ensuring legal certainty for businesses, making sure they know which regulations will apply to their specific activities. For private entities, small changes in the regulation can have important impacts on compliance and logistical costs, hence the importance of stability of regulations and thus the importance of a dedicated legal framework. In addition, legal frameworks, by playing with the strictness of requirements of the regulating authorities, can become more or less attractive compared to ones of other nations conducting space activities. While we are applying it to the space sector, this impact of the legal environment on the dynamics of business ecosystems has long been documents by the World Bank in its annual Doing Business studies[52].

This is particularly true of the conduct of the conduct of space activities in the fields of space safety and space resources utilization (SRU). Indeed, both fields are at the forefront of space activities worldwide and they are a lever for specialization of a country's space program. While space safety issues are determinant for a country's technical and diplomatic influence in space, SRU activities also matter business-wide, as they are highly promising opportunities susceptible of attracting massive investments. It thus becomes evident how a properly designed legal framework, one that is both stable in time yet flexible enough to be attractive to new businesses, will become an asset should Poland adopt such a legal framework.

Therefore, with the new ambitions of Poland in space and given the absence of a dedicated "space law" in the country despite there being a law creating the Polish Space Agency, the creation of a dedicated legal framework for the conduct of space activities could benefit Polish ambitions. While a dedicated space law supplemented by domain-specific regulations that specify the law are the most common way forward for emerging space nations, it is not the only way to go for Poland. Instead of having an overarching Space Law, Poland could indeed develop domain-specific regulations for space safety and SRU activities that would expand on laws enacted in relevant fields like industrial activity, the Polish economy, Poland's R&D activities or national defence.

Legal considerations necessarily take time for their implementation, due to the number of parties to get involved, the procedures involved, and the importance of carefully thinking and drafting laws and regulations. While Poland has just renewed its executive power through the Presidential elections of July 2020, the political landscape in the country is tight given that the Senate is in the hands of the opposition and the governmental majority at the assembly is short. This implies that consensus needs to be reached in order to advance quickly on the passing of new laws. However, given the generally more consensual nature of space activities and their strategic importance for the country, it is also possible that a consensus will be easily reached in Poland. In case of political blockage, having recourse to domain-specific regulations from the hands of the executive power only, would allow things to go faster for Poland.

Timeline and milestones

Overall, it is thus expected that a minimal timeline of one year for the preparation, vote and enactment of a national space law for Poland is going to be necessary. This timeline could expand to two years when including domain-specific that could accompany the space law, with a dedicated SRU regulation for example. This delay could be shortened if preparatory work is performed in parallel to the preparation of a Space Law, or if a regulations-only approach fully dedicated to space safety and SRU regulation is chosen.

[52] https://www.doingbusiness.org/

4.1 Priority 4: Increase awareness on space sustainability

Space activity brings a range of benefits to the terrestrial economy through both the creation of economic activity and through tangible benefits that improve the quality of life of users, therefore it is in the best interest of any space agency that sustained space activity remains possible and feasible.

Like any activity, space activity has an environmental impact. Unique among economic sectors, however, space activity affects not just the terrestrial environment, but the space environment as well. Regarding the former, space activity consumes energy and materials, and leads to the production of waste and emissions, all of which cause impacts to the Earth environment. Regarding the latter, however, unrestricted use of space can also pollute the space environment, such as through the generation of space debris, the crowding of radio bands or the reflection of light. Such pollution can complicate the use of the space environment in best cases, and outright render space unusable in the worst case.

While space sustainability is still an emerging field, it is clear that the continued and sustained use of space is contingent on the protection of both the space and terrestrial environments. Within the frame of increasing use of space (through more emerging space nations and private actors launching increasingly larger constellations) and of the ongoing environmental crisis, such concerns are more relevant now than ever before. Thus, for the long-term sustainable growth of the Polish space industry, it is in POLSA's immediate best interest to increase awareness of this topic and familiarise its own industry with the space sustainability.

Timeline and milestones

With the rapid development of the space industry in Poland since the nation joined the European Space Agency, it would be prudent take space sustainability seriously from as early as possible. Firstly, this would give the Polish industry an early adopter advantage and ensure that the industry tends towards sustainable practices early on, rather than spending resources on practices that will become obsolete due to environmental or regulatory pressures. Secondly, this would keep the Polish industry at the cutting edge of technologies related to space sustainability that may become critical in the future, such as SSA algorithms or “green” propellants. This would also improve the Polish industry’s access to income from projects that require demonstrations of sustainable technologies, such as those funded under the EU Green Deal. Thirdly, the increasing importance of sustainability on a global scale (increased public awareness, public initiatives such as the EU Green Deal) will afford reputational and network benefits to industrial actors that consider sustainability, and will afford soft power benefits to the national governments that provide an enabling infrastructure for such industrial actors.

5 Recommendations

This section identifies and details the potential actions that can be carried out by the Polish Space Agency in order to grasp the opportunities that could be pursued by Poland within the development of Space Safety activities and initiatives. A set of four recommendations is proposed, which entail in total 12 actions that could be implemented by POLSA and Poland to prepare the ground to the emergence of Space Safety activities.

The following figure provides an overview of the different recommendations issued by PwC to POLSA and Poland as a Space nation:

Figure 19: Overview of recommendations and associated actions

Recommendations		Potential Actions
Develop a favourable ecosystem allowing Polish companies to grow within Space Sustainability opportunities	1.1	Participate to discussions defining new standards
	1.2	Set up grants and prizes
	1.3	Disseminate knowledge through Workshops and Conventions
Develop Poland's strategic autonomy in the field of Space Sustainability	2.1	Identify critical technologies where European or indigenous Polish capabilities could be developed
	2.2	Use Polish capabilities in the field of Space Sustainability as a bartering tool
Develop Poland's legal framework for Space Sustainability and Space Resource Utilisation activities	3.1	Draft a "legislation of Space Activities" or a "Polish Space law" covering the various segments of space activities in Poland
	3.2	Draft a regulation on space safety activities in complement to the proposed Polish Space Law
	3.3	Disseminate knowledge through Workshops and Conventions
	3.4	Disseminate knowledge through Workshops and Conventions
Promote awareness on space sustainability	4.1	Define achievable space sustainability objectives
	4.2	Set up grants and financial tools to study the environmental impacts of space
	4.3	Set up workshops and conventions of the Polish space industry to spread awareness of space sustainability

5.1 Recommendation 1 – Develop a favourable ecosystem allowing Polish companies to grow within Space Sustainability opportunities

The first recommendation provided by PwC aims at supporting Poland in achieving the first priority identified in the previous section. This priority consists of supporting and enhancing the positioning of Polish Space companies in the field of Space Sustainability. Several economic and technological opportunities are nested in the challenges posed by the necessity to sustain a safe space environment. POLSA and other decision making actors in Poland could use this opportunity to foster the development of Polish Space companies.

In order to achieve such priority, a set of three actions has been identified by PwC:

- **Action 1.1 – Participate to discussions defining new standards:** Poland could engage in the definition of new standards related to the development of Space Sustainability activities to ensure that standards account for the Polish industry and are aligned with its interests.
- **Action 1.2 – Set up grants and prizes:** Poland could support high risk projects, encourage Polish firms to develop capabilities in processing space surveillance data, and ADR/IOS activities by supporting them through grant and prizes schemes.
- **Action 1.3 – Disseminate knowledge through Workshops and Conventions:** POLSA could lead knowledge sharing initiatives across the national industry in order to strengthen and harmonise best practices.

The following sections detail each recommended action listed above.

5.1.1 Action 1.1 – Participate to discussions defining new standards

The expected arrival of new guidelines, standards, certification processes and regulatory items aimed at enhancing the safety of the space environment may have several impacts on the current and future activities of the Polish ecosystem of space actors. In order to ensure the sustainability of the range Polish companies who may engage in Space Sustainability activities, it seems important to act to identify the best interests of such flora of Polish Space actors, and dispose of the adequate tools and network to defend these interests while new guidelines, standards and regulations are being discussed and harmonised at international level. Therefore, Poland should increase and consolidated its presence and involvement within international organizations where future guidelines and standards related to Space Sustainability will be discussed and harmonised. Poland should be able to justify such an international positioning and stature thanks to its dynamic and diverse ecosystem of space actors bringing novelty and innovative concepts in various fields to the international space community.

It is suggested for Polish representatives to propose standards that are concise and easy to follow. Simple and understandable standards would favour the development of Polish SMEs that do not necessarily have a large experience when dealing with and applying standards. Such standards would protect existing businesses and support the development of players who would be inclined to develop solutions in the field of Space Sustainability.

Required Capabilities

The capabilities required to develop new standards in the field of Space Sustainability and Safety are not material, and are rather based on networking capabilities with the set of international and European standardisation bodies, and the ability to network and federate the ecosystem of Polish entities in order to collect and map their different needs in the field of standardisation.

Stakeholder involved

Policy makers would play a major role in keeping these guidelines and standards easy to navigate as they would be the one to directly impact the decisions process at international and national level. POLSA, Interministerial Group for Space Policy in Poland, the Polish Space Industry Association (ZPSK) and the Polish Space Professionals Association are the Polish national stakeholders who should participate to this action.

POLSA would have to cooperate with other national space agencies to create and develop standards related to Space Sustainability and find a way to defend its interests. Therefore, POLSA could influence international organisations incentives (such as UN or ITU) to simplify the international regulatory framework. To define those standards and guidelines it would be important to rely on the knowledge and experience of users and standardisation bodies (ISO, CEN/CENELEC, ETSI, ECSS, CCSDS).

Expected Impacts

By participating to international discussions on the definition of new guidelines and standards related to Space Sustainability, Poland would extend and consolidate its network of international partners, and be able to fully defend its positioning on the international market. Such positioning would generate a strategic impact, as Poland would have the opportunity to further defend the best interests of its ecosystem of space actors and would also be able to strengthen its ties with international partners.

Standards adapted to Polish needs would enhance the competitiveness of Polish space companies on the European and global market. The provision of a concise and clear set of standards would protect the best interests of the ecosystem of Polish space actors. A clear understanding of the different objectives and incentives of Polish actors would allow POLSA and Polish decision representatives to avoid the development of standards that would hinder the sustainability of Polish space activities. Indeed, some entities may require support from specific legal expertise and/or spend additional time to ensure that standards and regulations are properly understood, and that the organizations activities will effectively comply with these standardization and regulatory requirements.

Key success factors

In order to successfully conduct Action 1.1, PwC has identified the following key success factors:

Engage with Polish ecosystem of space actors: POLSA should extensively communicate toward its industrials about the need for harmonization of guidelines and standards to create awareness and call for active participation of the private sector in related publicly-led discussions.

Defend the rationale and purpose of Poland's involvement in international discussions: The need for Poland to consolidate its presence among international bodies must be clearly expressed and justified by the fact that the country hosts an important flora of actors who contribute to the development and innovation of space activities at national, European and Global level. Therefore, the country should be entitled to have an important weight in the discussions deciding of the future guidelines and standards for space safety.

National standards and certification processes should be adapted to all commercial space players: With the collection of the different stakeholders needs including new commercial entrants, Poland should define standards and certification processes that would be helpful and easy to use for all players. As not everything can be done in parallel, a prioritization would be established to answer the most urgent needs.

Figure 20: Summary of Action 1.1

Required capabilities	Expected Impacts
• Networking capabilities with existing standardisation bodies • Federation of Polish space entities for the identification of their standardisation needs	• Enhancement of completeness of Polish space companies • Consolidation of Poland's network of international partners
Stakeholders involved	**Key Success Factors**
• POLSA • Interministerial Group for Space Policy in Poland • Polish Space Industry Association (ZPSK) • Polish Space Professionals Association	• Engage with Polish ecosystem of space actors • Defend the rationale and purpose of Poland's involvement in international discussions • National standards and certification processes should be adapted to all commercial space players

5.1.2 Action 1.2 – Set up grants and prizes

Poland could support high risk projects, encourage Polish firms to develop capabilities in processing space surveillance data, and ADR/IOS activities by supporting them through grant and prizes schemes. This would encourage Polish Space companies to develop innovative and competitive concepts in the field of Space Sustainability.

Required Capabilities

Funding capabilities would be required to develop this action. Such funding could come from several sources such as public investments from a dedicated national programme aiming at developing Space Sustainability concepts and/or private funding from investors and business angles who would be attracted by the Polish landscape and ecosystem.

Stakeholder involved

The set of Polish stakeholders involved in setting up grants and prizes to encourage the creation of innovative concepts in the field of Space Sustainability would be expected to be composed of the following:

- **The Ministry of Entrepreneurship and Technology** (MPiT) would have the ability to communicate on such grants and prizes opportunities with the Polish ecosystem of commercial actors. In addition, the MPiT would also have a clear understanding of EU policies developed in this field and would be a suitable actor for the selection of relevant candidates.
- **The Ministry of Science and Higher Education** (MNiSW) would connect with the national scientific and academia community who would also have an interest in participating as candidates to such grants and prizes.
- **The Industrial Development Agency** would also promote and support the organisation of the envisioned grants and prizes.
- **POLSA** would ensure the technical evaluation of the different concepts and ideas that would candidate to receive grants and prizes.

Expected Impacts

If Poland does indeed develop a funding mechanism to support IOS/ADR business models, and innovative solutions in the field of SST data processing and analysis would result in key strategic impacts. Indeed, such a funding program would foster innovation within Poland, boost competitiveness, attract talent and a flora of start-ups. As such, many of the benefits that can be potentially reaped would include the diversification of Poland's space economy, extending skills in the sector, and providing an international dimension to the activities. In addition IOS/ADR are technologies of scope and to some degree some of the technologies needed for IOS/ADR can be spun-towards SRU. These transferrable technologies include components such as robotic arms, docking stations as well as the technology to refuel in micro gravity. As such development/investment made towards ADR/IOS could support and accelerate a potential SRU program too.

Key success factors

Select companies entailing scalability in their services: The key differentiator of the most optimal profile should be the company's ability to propose scalable solutions. For instance, in the field of ADR, relevant candidate companies should propose concepts allowing docking operations with large number of different types of spacecraft. As another example, in the field of SST data processing and analysis, companies should demonstrate the ability to integrate data from different data sets.

Support should be awarded to companies with clearly identifiable and demonstrable potential revenue streams: The biggest show stopper for Active Debris Removal projects is the identification of payers. Indeed, even though the global space community acknowledges the need to reduce the number of orbital debris, the direct commercial benefit resulting from the removal of one debris is still difficult to perceive. Only Space agencies and institutions can kick start the development of ADR by providing anchor contracts with players owning a mature technical solution.

Develop funding initiatives in coherence with new standards: It is vital that funding tools and mechanisms are developed alongside the set of standards framing space sustainability activities and the two must go hand in hand for increased overall success.

Figure 21: Summary of action 1.2

Required capabilities	Expected Impacts
• Funding capabilities	• Foster innovation within Poland • Boost Polish competitiveness and attract talent • Allow the diversification of Poland's space economy

Stakeholders involved	Key Success Factors
• Ministry of Entrepreneurship and Technology (MPiT) • Ministry of Science and Higher Education • Industrial Development Agency • POLSA	• Select companies entailing scalability in their services • Support should be awarded to companies with clearly identifiable and demonstrable potential revenue streams • Develop funding initiatives in coherence with new standards

5.1.1 Action 1.3 – Disseminate knowledge through Workshops and Conventions

POLSA could lead knowledge sharing initiatives across the national industry in order to strengthen and harmonise best practices. This action would allow the Polish Space sector to stay informed on the different trends of the market related to Space sustainability and be prepared to develop innovative solutions and concepts in this field. In addition, national space systems developers, operators and other Polish entities carrying out space activities would increase their knowledge and understanding of Space Sustainability matters and adapt their activities in order to preserve the sustainability of the space environment.

Required Capabilities

In order to provide active market intelligence to the ecosystem of Polish space entities, POLSA would require the production of some sort of annual report providing such information. In addition, the organisation of Workshops and Conventions would require the identification of a suitable time to gather a large number of Polish players. Communication and networking capabilities with the ecosystem of Polish stakeholders and actors involved in space would also be required.

Stakeholder involved

In addition to the whole set of Polish space companies involved in the Ministry of Entrepreneurship and Technology (MPiT) and the Industrial Development Agency would dispose of the network and communication capabilities to reach the different Polish actors who might be interested in the topic of Space Sustainability. POLSA could organise and facilitate the occurrence of these workshops and conferences.

Expected Impacts

The dissemination of information related to Space Sustainability would allow Polish space entities to increase their understanding of this domain and identify potential opportunities that can be matched by their existing capabilities. In addition, the organisation of conferences and workshops would open opportunities for Polish space companies to network and create potential partnerships and synergies toward the development of innovative concepts.

Key success factors

Associate workshops and conferences on Space Sustainability: In order to access the largest set of Polish stakeholders, conference and workshops on the topic of Space Sustainability and its associated opportunities could be coupled with other events related to the space sector.

Directly involve Polish space entities by collecting their feedback on their perception of Space sustainability matters and opportunities: One way of communicating on the topic of Space Sustainability would be to directly involve Polish entities through dedicated discussions, collecting the view of the Polish industry on the different opportunities that are perceived.

Figure 22: Summary of Action 1.3

Required capabilities

- Identification of suitable timeslot allowing the gathering of an exhaustive set of actors
- Communication and networking capabilities

Expected Impacts

- Allow Polish entities to identify opportunities in the field of Space Sustainability
- Create opportunities for Polish entities to cooperate and create synergies

Stakeholders involved

- Ministry of Entrepreneurship and Technology (MPiT)
- Industrial Development Agency
- POLSA

Key Success Factors

- Associate workshops and conferences on Space Sustainability
- Directly involve Polish space entities by collecting their feedback on their perception of Space sustainability matters and opportunities

5.2 Recommendation 2 – Develop Poland’s strategic autonomy in the field of Space Sustainability

The second recommendation provided by PwC is that Poland strengthens its position at global level in the field of Space Sustainability by leveraging on its consolidated position at European level. Poland has the right set of capabilities and a promising ecosystem of actors to become a leading nation at global level in the field of Space Sustainability. In order to achieve such vision, PwC has identified two key actions that could be pursued by Poland:

- **Action 2.1 – Identify critical technologies where European or indigenous Polish capabilities could be developed:** The current SSA landscape is dominated by foreign nations, POLSA can host or create expert working groups to identify critical technologies for which Poland is dependent on foreign actors. Technologies can be grouped by those that Poland can develop indigenously and can develop in co-operation with EU actors.
- **Action 2.2 – Use Polish capabilities in the field of Space Sustainability as a bartering tool:** In order to enhanced it's positioning in the EU and globally, Poland could use it's set of capabilities for SSA and space sustainability activities as bartering tools. This would be materialised through data sharing agreements, and would allow Poland to access technology and information developed by third countries that could be beneficial to Poland on the medium and long term.

The following sections detail these proposed actions.

5.2.1 Action 2.1 – Identify critical technologies where European or indigenous Polish capabilities could be developed

The current SSA landscape is dominated by foreign nations, which are mainly based in the US. The SPD3 is also expected to increase the presence of US-based companies in the field of Space Sustainability activities. In order to reduce its dependency on foreign entities in the field of Space Sustainability, POLSA can host or create expert working groups to identify critical technologies for which Poland is dependent on foreign actors. Technologies can be grouped by those that Poland can develop indigenously and can develop in co-operation with EU actors.

Required Capabilities

This action would have to be implemented with support from research capabilities and infrastructure. The identification of gaps would require synchronised research across Europe in order to avoid duplication of efforts and overlaps.

Stakeholder involved

In order to identify and pursue opportunities in the field of Space Sustainability that would reinforce Poland and Europe’s autonomy, Poland should discuss and coordinate with European bodies already involved in such action such as ESA and European Commission. In addition, POLSA should pursue the identification of gaps that could be filled by Europe with the other EU SST Consortium members.

Expected Impacts

The identification of current Polish and EU capabilities with respect to foreign technologies would allow the deployment of activities in key strategic areas of Space Sustainability and provide Poland and Europe with a competitive advantage.

Key success factors

Engage in discussions with international players to identify their specific needs and gaps: Poland should interact with global entities developing Space Sustainability activities as well as the user community in order to clearly identify gaps that can be filled.

Develop Poland’s potential in areas that are identified as gaps at global level: Once gaps will be identified, Poland should invest on its existing capabilities or nascent capabilities which could result in gaps fillers once matured and developed.

Figure 23: Summary of Action 2.1

Required capabilities	Expected Impacts
• Research capabilities and infrastructure	• Competitive advantage

Stakeholders involved	Key Success Factors
• Committee on Space Research of the Polish Academy of Sciences (KBKiS PAN) • ESA • European Commission • Other EU SST Consortium members	• Engage in discussions with international players to identify their specific needs and gaps • Develop Poland's potential in areas that are identified as gaps at global level

5.2.2 Action 2.2 – Use Polish capabilities in the field of Space Sustainability as a bartering tool

In order to enhanced it's positioning in the EU and globally, Poland could use it's set of capabilities for SSA and space sustainability activities as bartering tools. This would be materialised through data sharing agreements, and would allow Poland to access technology and information developed by third countries that could be beneficial to Poland on the medium and long term.

Required Capabilities

Networking capabilities with foreign countries and third parties would be required to use Polish capabilities as a bartering tool. In addition, in order to concretise additional partnership involving the usage of Polish SSA capabilities as a bartering tool, clear and understandable material highlighting the characteristics and features of Polish capabilities should be developed.

Stakeholder involved

POLSA would develop the description of Poland's set of capabilities and identify the potential partners who might have an interest in collaborating with Poland. The Polish Ministry of Foreign Affairs could facilitate the networking opportunities between Poland and third parties around collaborating schemes involving Polish capabilities in the field of Space Sustainability.

Expected Impacts

The usage of Polish SSA capabilities as a bartering tool would allow Poland to expand its network of partners in the field of Space Sustainability. In return for the provision of access to data produced with Polish capabilities, Poland could access other resources related to Space, such as ground systems network for supporting the operation of Polish satellites for instance.

Key success factors

Identify the specific needs in terms of Space Sustainability across regions of interest: Poland should investigate on the Space Sustainability needs that could be expressed by emerging space nations for instance who have launched space programmes and space infrastructure and who are seeking for space observation information to ensure the safety of their assets.

Identify and list the set of capabilities which could be accessible to Poland in return of the provision of Space Sustainability capabilities: Poland should examine what benefits and capabilities could be brought to Poland.

Figure 24: Summary of Action 2.2

Required capabilities	Expected Impacts
• Description of features and characteristics of Polish capabilities	• Expansion of Poland's network of partners • Access to capabilities supporting and facilitating Polish space activities
Stakeholders involved	**Key Success Factors**
• POLSA • Polish Ministry of Foreign Affairs	• Identify the specific needs in terms of Space Sustainability across regions of interest • Identify and list the set of capabilities which could be accessible to Poland in return of the provision of Space Sustainability capabilities

5.3 Recommendation 3 – Develop Poland's legal framework for Space Sustainability and Space Resource Utilisation activities

The third recommendation suggested by PwC is to develop space-specific legal documents including a national space law, regulations for the priority domains of space safety and space resources utilization (SRU). In addition, PwC believes that joining the Artemis Accords could be a strong signal given to the international space community as it will display Poland's ambitions in space by entering Accords that have a focus on SRU and a deep consideration for space safety issues, in a context where Poland has major partner onboard the Accords through the USA, Italy and Luxembourg.

This recommendation will help build a legal framework for space activities in Poland that will reassure stakeholders, both public and private. It will provide solid legal grounds to the development of space activities, thereby protecting the activities to be developed by ensuring legal certainty anchored in easily identifiable legal sources. This will, in return, increase the attractiveness of the Polish ecosystem overall, facilitating business activity but also providing a legal framework that, if designed properly, could be more attractive than neighbouring countries and therefore attract companies to set-up shop in Poland.

Thus, the overall added-value expected is to position Poland within the circle of nations with a dedicated legal environment to space activities that is both business-friendly and compliant with stringent standards in terms of space safety, making Poland a privileged partner internationally.

5.3.1 Action 3.1 – Draft a "legislation of Space Activities" or a "Polish Space law" covering the various segments of space activities in Poland

PwC strongly believes that Polish space activities could strongly benefit from a dedicated space law governing all space activities. This is expected to provide a strong framework for Polish public and private entities engaged in activities related to the space sector, and will also become a lever of attractiveness for Poland's space economy. Overall it is expected that a dedicated space law will strengthen the position of Poland as a nation fully engaged in the development of the national, European and international space ecosystem. PwC believes that the current absence of such a legal framework creates uncertainty to space players and partners as to which regulations apply to activities involving space and as such is becoming a liability that could be overcome.

Required Capabilities

The development of a Polish Space Law has the advantage of not requiring any specific infrastructure but instead focuses on manpower. In order to develop a proper legal framework, several expertise need to be brought together. They include technical expertise from space specialists in all the different fields that will be covered by the legislation, in order to understand if the technical elements that need regulation are covered and if the regulation does not prevent the proper development of space capabilities. In parallel, business specialists are encouraged to be involved, as they will be the best ones able to understand the business-friendly nature of the legal environment that will be development. Finally, these inputs will need to be wrapped up by experts in legal drafting in order to ensure proper preparation of the legal documents.

Given the specific nature of this action 3.1, it is also important to secure a political platform that will involve a dialogue between the Polish Space Agency (POLSA), the Polish government and the Polish parliament who will ultimately be in charge of voting the proposed space law.

Stakeholder involved

We anticipate 4 types of stakeholders to be involved in the drafting of a Polish Space Law as it is currently proposed:

- **The Polish Space Agency and its experts** will provide the space expertise required to understand what needs to fall under the Polish Space Law and how technical experts are expecting space activities to be regulated. The direct interest of this stakeholder will be that it will see its activities regulated through that new piece of legislation, thus strengthening the foundations of its authority. This will be directly relevant for the regulation of space safety and SRU activities.
- **Polish political authorities**, including Polish government and Polish parliament, represent the mandatory political backbone of the Polish Space Law as they are key in the voting of the law and its enactment.
- **Participants from the Polish Space Industry and business ecosystem** will provide their understanding of what is needed to provide an attractive legal framework for space activities in Poland. Their input will thus directly be used to create a framework that attracts businesses and facilitates doing business in the space sector. This will be particularly relevant for the regulation of SRU activities.
- **Legal experts** will necessary be involved in the drafting process of the space law and will either come from governmental entities like members of executive cabinets, legal experts from the Polish Space Agency, and could also be external space law experts onboarded specifically for the drafting of the Polish Space Law.

Expected Impacts

The drafting and enactment of a new Polish Space Law or legal framework in general is expected to bring more attractiveness of Poland for space industry’s players and will fully unlock the potential of future Polish space projects. By adopting a Space Law, Poland will secure its legal framework and create more legal certainty for the space industry. This is expected to have an impact on attractiveness of key space players who will feel more certain about the future evolutions of regulations in the country and will also strengthen the position of Poland in the circle of nations with a dedicated space law. This will also provide more stable grounds for the development of novel activities that will be newly regulated, including space safety and SRU activities. Indeed, with a proper legal framework that regulates such activities, it will be easier for Poland to engage into bilateral agreements or international cooperation overall.

Key success factors

The success of Action 3.1 lies in a series of cooperation between entities. Such cooperation is not always easy to achieve, especially because it implies the participation of political actors. The main key success factors expected and risks associated are the following:

- **Cooperation of the Polish Government and lawmakers** (Parliament) in the project is essential as without their agreement, the project of a Space Law will not materialize. Risks exist, as the Polish Senate is in the hands of the opposition and the majority of the ruling party is weak. Therefore, political consensus on the project will need to be reached, but the rather consensual nature of space activities could facilitate the process

- **Fruitful dialogue between different actors** is also a key success factor as the project of a Polish Space Law will require the cooperation of technical experts, lawyers and business actors who all bring different expertise and points of view. The ability of an entity like the Polish Space Agency to create a successful dialogue platform to draft the Polish Space Law will therefore be decisive in the success of the project.

Figure 25: Summary of Action 3.1

Required capabilities

- Specific knowhow in technical requirements of the conduct of space activities
- Legal expertise in the drafting of national laws and regulations
- Experts from the business world able to understand how to use laws & regulations at the benefit of a business-friendly ecosystem
- Secure a political platform for dialogue between the POLSA, the Polish governments and the Polish Parliament

Expected Impacts

- Legal certainty
- Business attractiveness
- Increased influence in the space sector

Stakeholders involved

- Legal Experts
- Industrials & Business Experts
- POLSA & Technical Experts
- Political Authorities

Key Success Factors

- Cooperation of the Polish government and Polish lawmakers
- Fruitful dialogue between stakeholders involved

5.3.2 Action 3.2 – Draft a regulation on space safety activities in complement to the proposed Polish Space Law

Developing a dedicated regulation of space safety activities would be a means of digging deeper into domain specific regulations. While a Polish Space Law is a generalist legal document that tends to be rigid in the sense that it is difficult to amend, regulations are more details pieces of legislation that are easier to modify along with industry changes.

Because space safety is an activity that is susceptible of rapid changes linked to technological evolutions and relies heavily on cooperation initiatives, it is considered that a dedicated regulation, and the ease of amendment it entails, will ensure that future changes in the space safety domain will more rapidly be implemented than with a more rigid framework that a law would represent. Therefore, the model of a generalist space law, completed by sector-specific regulations would be privileged by PwC.

The existence of a domain specific regulation is also seen as a strong asset in expanding the partnerships of Poland with other institutional players active in the domain of space safety as it will send a strong signal of the desire of Poland to develop a proper, stable legal framework in the field.

Required Capabilities

In order to develop a proper space safety regulation, Poland will require the proper knowhow and manpower with experts in both technical and legal aspects of the space sector who will contribute to the attractiveness of the space safety regulations. This requirement is similar to the ones of Action 3.1.

However, in addition, a regulation is generally expected to come as a complement to a more generalist space law. Therefore, PwC considers the space safety specific regulation to be a complement to the generalist Space Law that it proposes for Poland. Thus, a pre-existing legal framework for space activities is here seen as a required capability to move forward.

Finally, it will be important to mobilize the network of partners of Poland in the field of space safety activities, as coordination in the regulation of such activities is essential to its success. Such partners include international governments, European initiatives or NATO.

Stakeholder involved

PwC anticipates 4 types of stakeholders to be involved in the effort of joining the Artemis Accords:

- **The Polish Space Agency and its experts** will help understand the type of activities to be regulated from a technical point of view and will also provide the policy guidance of the regulation, orienting its content towards the activities that are present in the Polish Space Program.
- **The Polish Government,** pending on specifications of Polish law, might be able to issue regulations by its own without having recourse to the Parliament[53]. This would allow for the process of regulation space safety activities to be both quicker and be less prone to political blockage.
- **Space Safety international partners of Poland** will also be crucial in the success of the regulation, since they will share their experience and expertise on regulating such type of activities, also providing a benchmark for Poland. In addition, it is recommended that Polish regulations be at par with that of its space safety partners in order to facilitate future collaborations.
- **Legal experts** will necessary be involved in the drafting process of a space safety regulation and will either come from governmental entities like members of executive cabinets, legal experts from the Polish Space Agency, and could also be external space law experts onboarded specifically for the drafting of a regulation.

Expected Impacts

The benefit of a dedicated space safety activities' regulation is to be sought out of the provision of additional legal certainty to public and private players who want to engage in such activities and set-up shop in Poland. This legal certainty comes with more attractiveness if the framework associated is pro-business enough when it comes to the conduct of space safety activities.

In addition, a regulation is easier to change for policy makers. As such, it will facilitate future adaptations to a changing technological, the Polish government and Polish Space Agency therefore not having to systematically revert to a revision of the law.

A dedicated regulation of space safety activities is also a strong signal towards the space safety domain partners of Poland, especially on the institutional side. It shows a desire to provide strong legal groundings for future collaborations, including those with NATO, provided that regulations are at par with what Poland's partners are doing.

Key success factors

Key success factors of drafting a proper space safety regulation (Action 3.2) include:

- **Prior existence of a Polish Space Law** will facilitate the development of a space safety regulation but is not mandatory as the Polish Government might still be able to regulate space safety activities without a pre-existing Space Law.
- **Capacity of the Polish Government to draft a regulation** with the authorization of the Polish lawmakers in order to move quickly and with sufficient margins.
- **Proper involvement of current space safety partners of Poland** including NATO and the United States in order to develop a regulation of space safety activities that is compatible with the cooperation initiatives in existence.

[53] This however might be conditional on a preliminary authorization through a Polish Space Law that would authorize the government to issue regulations without Parliament's approval.

Figure 26: Summary of Action 3.2

Required capabilities

- Specific knowhow related to technical and legal aspects of space activities as mentioned in Action 3.1
- The existence of a Polish Space Law or the authorization to the Government to regulate space safety activities
- Coordination with the network of Polish partners in the domain of space safety

Expected Impacts

- Additional legal certainty to public and private players engaged in space safety activities
- Facilitated adaptation to future changes in the domain
- Strengthening of institutional partnerships internationally

Stakeholders involved

- Legal Experts
- Space safety international partners
- POLSA & Technical Experts
- Political Authorities

Key Success Factors

- Prior existence of a Polish Space Law
- Capacity of the Polish Government to draft a regulation
- Proper involvement of current space safety partners of Poland

5.3.3 Action 3.3 – Draft a regulation on Space Resources Utilisation (SRU) activities in complement to the proposed Polish Space Law

PwC recommends that Poland develops a regulation on the conduct of SRU activities to complement the proposed Polish Space Law. While a Polish Space Law is a generalist legal document that tends to be rigid in the sense that it is difficult to amend, regulations are more details pieces of legislation that are easier to modify along with industry changes. Therefore the format of a regulations seems appropriate for SRU activities given that they are a novel space domain that will inevitably evolve in the coming years.

Space Resources Utilization (SRU) activities are a booming trend in the space economy, as they are an important financial prospect in the industry and a growing number of companies, from start-ups to international companies, are growing ambitions to develop SRU activities. On the other hand, SRU activities are still subject to legal uncertainties as legal interpretation of the various international treaties surrounding the exploitation of resources in outer space and on celestial bodies is subject to diverging interpretations. Therefore, a growing number of space nations are developing dedicated regulations for SRU activities that provide protection of entities setting-up shop to conduct such activities. Luxembourg, the United States or the United Arab Emirates are the most common examples and are singing members of the Artemis Accords along with six other partners, Accords that go in the direction of legitimizing the compatibility of SRU activities with the existing body of international law.

Required Capabilities

In order to develop a proper SRU regulation, Poland will require the proper knowhow and manpower with experts in both technical and legal aspects of the space sector, as well as business experts who will be able to determine which factors will contribute to the attractiveness of the SRU regulations for international private players looking to locate their activities in Poland. This requirement is similar to the ones of Action 3.1.

However, in addition, a regulation is generally expected to come as a complement to a more generalist space law. Therefore, PwC considers the SRU specific regulation to be a complement to the generalist Space Law that it proposes for Poland. Thus, a pre-existing legal framework for space activities is here seen as a required capability to move forward.

Stakeholder involved

PwC anticipates 4 types of stakeholders to be involved in the effort of joining the Artemis Accords:

- **The Polish Space Agency and its experts** will help understand the type of activities to be regulated from a technical point of view and will also provide the policy guidance of the regulation, orienting its content towards the activities that are present in the Polish Space Program.

- **The Polish Government,** pending on specifications of Polish law, might be able to issue regulations by its own without having recourse to the Parliament[54]. This would allow for the process of regulation SRU activities to be both quicker and be less prone to political blockage.
- **Participants from the Polish Space Industry and business ecosystem** will provide their understanding of what is needed to provide an attractive legal framework for SRU activities in Poland. Their input will thus directly be used to create a framework that attracts businesses and facilitates doing business in the space sector.
- **Legal experts** will necessary be involved in the drafting process of a SRU regulation and will either come from governmental entities like members of executive cabinets, legal experts from the Polish Space Agency, and could also be external space law experts onboarded specifically for the drafting of a regulation.

Expected Impacts

Having dedicated regulations for SRU activities will be a means of providing additional legal certainty to public and private players who want to engage in such activities and set-up shop in Poland. This legal certainty comes with more attractiveness if the framework associated is pro-business enough when it comes to the conduct of SRU activities.

In addition, a regulation is easier to change for policy makers. As such, it will facilitate future adaptations to a changing technological and economic environment, the Polish government and Polish Space Agency therefore not having to systematically revert to a revision of the law. This is also a guarantee for SRU actors in Poland that their regulating framework will be adaptative to account for the latest changes in the space ecosystem. It will also send a strong signal to potential international partners, including the signatory countries of the Artemis Accords (see Action 3.4).

Key success factors

Key success factors of drafting a proper SRU regulation (Action 3.3) include:

- **Prior existence of a Polish Space Law** will facilitate the development of a SRU regulation but is not mandatory as the Polish Government might still be able to regulate SRU activities without a pre-existing Space Law
- **Capacity of the Polish Government to draft a regulation** with the authorization of the Polish lawmakers in order to move quickly and with sufficient margins.
- **Ensure that the SRU regulations developed don’t create tensions with other partners** given the controversial nature of SRU activities. Indeed some Polish partners might criticize the country for its stance on allowing SRU activities and might want to put pressure on the country. Resisting such pressures and reassuring partners will be key in success.

[54] This however might be conditional on a preliminary authorization through a Polish Space Law that would authorize the government to issue regulations without Parliament’s approval.

Figure 27: Summary of Action 3.3

Required capabilities	Expected Impacts
• Specific knowhow related to technical and legal aspects of space activities as mentioned in Action 3.1 • The existence of a Polish Space Law or the authorization to the Government to regulate SRU activities	• Increased attractiveness for entities conducting SRU activities • Facilitated adaptation to future changes in the domain • Strong signal sent to prospective institutional partners conducting SRU activities

Stakeholders involved	Key Success Factors
• Legal Experts • Industrials & Business Experts • POLSA & Technical Experts • Political Authorities	• Prior existence of a Polish Space Law • Capacity of the Polish Government to draft a regulation • Ensure that SRU regulations developed don't create tensions with other partners

5.3.4 Action 3.4 – Make of Poland a signing party of the Artemis Accords

The Artemis Accords are a set of bilateral agreements between its signing member countries which comprise the United States, the United Arab Emirates, the United Kingdom, Ukraine, Australia, Japan, Canada as well as two EU member countries: Italy and Luxembourg.

The Artemis Accords are a new type of cooperation in the space sector and among their main preoccupations are the issues of space safety of in-orbit activities, focusing on a reasonable use of outer space, as well as the notion that space resources can be used by nations and their subsidiaries conducting activities in space, provided that they display a responsible and reasonable use of these resources on celestial bodies. Therefore, the Artemis Accords are often considered as a pro-SRU activities type of agreements.

PwC believes that entering the Artemis Accords will have several benefits for Poland. First it will reinforce the diplomatic weight of the country in the space sector, allowing Poland to join a rather exclusive club of space nations. Second, it will also send a strong signal to companies willing to develop SRU activities that might want to setup shop in Poland in the future, as being a signatory member of the Artemis Accords will materialize the desire of the country to be a leader in the field.

Required Capabilities

Capabilities required to join the Artemis Accords are like the other actions related to the legal field, mainly related to human capital and manpower. Therefore, the same sets of expertise as Action 4.1 are expected with the specificity that there is an international dimension to the Artemis Accords. This dimension will certainly required diplomatic intervention in the negotiation processes and shall involve strong cross-country dialogues with other signatory EU member states including Italy and Luxembourg. Therefore, this new European and International dimension is part of the specific capabilities required for Action 3.4.

In addition, it is also anticipated that joining the Artemis Accords will require from Poland a stronger engagement in the development of a space-dedicated legal framework. This is why joining the Artemis Accords comes as the fourth recommended Action in relations to the Polish legal framework, as PwC considers it tributary to the development of previous regulatory frameworks that will cover the conduct of space activities in relations to SRU.

Stakeholder involved

We anticipate 4 types of stakeholders to be involved in the effort of joining the Artemis Accords:

- **The Polish Space Agency and its experts** will be a key element in the inter-agency dialogue that is required in the proper success of Poland joining the Artemis Accords. Because space agencies are at the backbone of the Accords, heavy inter-agency dialogue will happen should Poland engage into negotiations to join the Accords.

- **Polish political authorities**, including Polish government and Polish parliament, represent the mandatory political backbone of joining the Artemis Accords, as they are an instrument of international law.
- **The diplomatic network of Poland** is also expected to be heavily involved at several scales. This includes the European level, where contacts between Poland, Italy and Luxembourg will be important, since they are signatory members and EU member states just like Poland. This includes inter-agency dialogue between space agencies including with the European Space Agency. Diplomatic dialogue with the European Union in order to explain the reasons behind the Polish desire to join the Accords is also expected. Finally, diplomatic relationships with the United States of America, at the core of the Artemis Accords will be mandatory.
- **Legal experts** will necessary be involved in the drafting process of the Artemis Accords and will either come from governmental entities like members of executive cabinets, legal experts from the Polish Space Agency, and could also be external space law experts onboarded specifically for the drafting of such an international agreement.

Expected Impacts

Joining the Artemis Accords will fist strengthen the position of Poland within the landscape of space nations, allowing the country to join an exclusive club of countries. In return, this will facilitate the cooperation in a variety of programs that naturally include space safety and SRU activities, two that are of high priority to Poland. This is true not only at the European level where Poland will join Italy and Luxembourg in the Accords but will also be true at the international level. Therefore, there is a diplomatic argument that is also attached to the signing of the Artemis Accords.

In addition, signing the Artemis Accords will also be a strong signal to public and private entities looking for a partner or country where to setup shop in, as the Artemis Accords have a strong focus on SRU activities and space safety. Therefore, it will also serve the Polish ambition to develop its positioning as one of the leaders in these two space domains.

Key success factors

Key success factors of joining the Artemis Accords (Action 3.4) include:

- **Cooperation of the Polish Government and lawmakers** (Parliament) in the project is essential as without their agreement, the project of joining the Artemis Accords will not materialize. Similar concerns as the ones expressed for Action 4.1, in relations to the political landscape of Poland apply to joining the Artemis Accords.
- **Negotiations with the other signing parties of the Artemis Accords** might fail and therefore it is essential to mobilize the full potential of the Polish diplomacy and the Polish Space Agency. To that effect, PwC considers that strong prior discussions with Polish EU member states partners who also signed the Artemis Accords, namely Italy and Luxembourg will be essential in the success of the initiative.

Figure 28: Summary of Action 3.4

Required capabilities

- Specific knowhow related to technical and legal aspects of space activities
- Pre-existing legal framework covering space activities, in particular in space safety and SRU
- Diplomatic intervention to support the negotiations of the Accords
- Political support from Polish Government and Parliament

Expected Impacts

- Increased overall diplomatic influence
- Increased influence in the space sector
- Increased attractiveness for entities conducting space safety and SRU activities

Stakeholders involved

- Legal Experts
- Polish diplomatic network
- POLSA & Technical Experts
- Political Authorities

Key Success Factors

- Cooperation of the Polish government and Polish lawmakers
- Negotiations with the other signing parties of the Artemis Accords

5.4 Recommendation 4 – Promote awareness on space sustainability

With the Polish space industry growing, and with rising concerns about the impacts of space activity on the terrestrial and space environment, PwC would recommend that the Polish Space Agency take action to increase the awareness of space sustainability issues in the Polish space industry. This recommendation stems from the benefits of the continued use of space, and the fact that unsustainable use of space will directly harm the terrestrial environment and potentially render the space environment economically inaccessible for future users.

It is our belief that improved awareness of space sustainability issues will not only encourage the development of more sustainable space practices, but will also have positive strategic implications for the Polish space industry. These would include ensuring that the Polish industry develops sustainable practices early on, rather than potentially developing dependence on unsustainable technologies and practices, as well as encouraging the indigenous development of future critical technologies.

To this end, the team proposes three actions to be taken in the short term that can support this recommendation.

5.4.1 Action 4.1 - Define achievable space sustainability objectives

The first step in disseminating space sustainability awareness among the industry would be to better understand both where the Polish space industry current stands and the ideal scenario of where it could be. This would entail some research into the space sustainability capabilities of the industry at present, as well as the technologies with the aim of the creation of a set of realistic space sustainability objectives for the industry.

The creation of a space sustainability objective list or roadmap would offer the Polish space industry some common goals with which they can be aligned. Such objectives could include commitments to reduction in space debris, commitments to reduction of use of hazardous substances, commitments to reduction in emissions.

Required Capabilities

In achievement of this action, POLSA would require a thorough understanding of the current state of play. This would include understanding of current industry initiatives related to the development of space sustainability related technology, the current level of technology related to space sustainability (such as green manufacturing, green propellants, SSA algorithms, etc.).

To undertake this, the Agency could involve industry and academic players in consultations or roundtable discussions to share information on the current state of play. Depending on the complexity of the current Polish space sustainability landscape, POLSA might need to involve more players or more analysts to develop more realistic objectives or a realistic roadmap.

Stakeholder involved

As mentioned above, POLSA would benefit from involving industry stakeholders with the aim of understanding whether these actors are undertaking any initiatives relevant to space sustainability, the maturity of these initiatives, and the current capabilities that industry holds. These industry actors would include manufacturers of space systems, operators of space systems, manufacturers of ground infrastructure, but also manufacturers from associated industries where developments may be leveraged by the space industry, such as in IT, semiconductors, radars, and so on

Similarly, POLSA could benefit from consulting with technical academic institutions to better understand the current state of the art, and the latest developments that could be made operational in the near future. Note that these institutions need not directly be directly involved in space, but could be involved in associated subjects such as those mentioned above.

Expected Impacts

A detailed and realistic set of objectives for the industry based on a proper understanding of the state of play and current capabilities would act as a lever towards nudging the industry in a direction that is in the best interests of the collective Polish space sector, providing a high level framework against which future public and industry actions can be aligned.

Key success factors

Successful achievement of this action would require a comprehensive understanding of the Polish space landscape. Without this, it is unlikely that the objectives would be a realistic reflection of the capabilities of the industry.

To ensure a realistic understanding, POLSA would benefit from interacting with comprehensive and representative firms within the industry. This would entail considering a diversity of actors, as representatives from different sub-industries, different firm sizes and different points on the value chain. Considering resource limitations, it would be prudent to consider a diversity rather than large number of actors.

Figure 29: Summary of Action 4.1

Required capabilities

- Comprehensive understanding of current space sustainability initiatives
- Comprehensive understanding of stat of current relevant technology and knowledge

Expected Impacts

- Improved understanding of the Polish space sustainability ecosystem
- Unified realistic guiding objective for the industry
- Alignment of POLSA and industry objectives on space sustainability

Stakeholders involved

- Space system manufacturers
- Satellite operators
- Associated industry
- Academic institutions

Key Success Factors

- Consideration of the diversity of capabilities in the Polish space ecosystem

5.4.2 Action 4.2 – Set up grants and financial tools to study the environmental impacts of space

An important step towards improved space sustainability would be to study the environmental impacts of space. This would entail examining and measuring environmental risks related to certain processes and materials that are commonly used in the space sector.

At the current state of play, addressing the environmental impact of space activity is difficult due to limited understanding of the current processes and interactions. With regards to the space environment, the risks of collisions associated with launches and orbital regimes is a variable that could be better understood. On Earth, the environmental impact of launch emissions in the different levels of the atmosphere and the associated impacts of re-entry are poorly understood. Similarly, due to the niche nature of the space industry, many processes and materials used in the space industry have environmental impacts that cannot be modelled through industry proxies.

PwC would recommend that the Polish Space Agency take an initiative, leveraging financial instruments at its disposal, to encourage the industry to assess their own practices to identify areas where there are current risks. Risk in this context can refer to physical risk due to pollution of the space and terrestrial environment, or in terms of regulatory risk wherein a hazardous material or process may be regulated more tightly in the future, drastically affecting supply.

Consider, for example, disruptions caused by the REACH regulation on industries that did not have replacements for materials regulated under REACH. Currently, hydrazine is listed as a substance of very high concern by the European Chemicals Agency, shedding some uncertainty on its future supply chain[55]. Proactive understanding of the risks associated with such materials can avoid shocks in the future.

The type of studies to be undertaken could fall into two main groups. The first would bee conventional studies, where firms could be encouraged to study the terrestrial environmental impacts of their own processes. This could entail measuring impacts where possible, or identifying substances or processes that present some environmental risks, or even identification of areas of improvement through introspection.

The second type of study would involve academic exercises to model more exotic environmental impacts (including those on the space environment), such as the impact of niche materials and processes in the space sector, the impact of rocket plumes and re-entry, development of models for space debris generation, and so on.

Required Capabilities

On POLSA's end, the required capabilities would be the capital that can be committed to this task. Allocating a reasonable amount would entail an understanding of the cost to undertake such research as well as understanding the industry well enough to assess the risk/reward for each project.

On the industry side, required capabilities would include the organisational ability to understand and transparently assess their supply chains when assessing conventional impacts on the terrestrial environment. Depending on the depth of the assessment, this could involve life cycle impact assessments for some of their products or processes.

When addressing the second type of impacts, which involve modelling the unconventional environmental impacts of extremely niche processes, additional capabilities would be required. Depending on the type of assessment, scientific knowledge in extremely specific domains might be required. Taking the earlier example of rocket plumes, a detailed understanding of and ability to model atmosphere dynamics would be needed for such a study.

Stakeholder involved

Studies into the environmental impact of space activities would require relatively high levels of industry participation, particularly from space system manufacturers, as the manufacture of space systems tends to require more niche processes and materials than those for the ground infrastructure or the downstream segment and is thus less well represented by generic proxies.

Similarly, participation from entities well versed in the assessment of environmental impacts, such as environmental analysts, environmental modelling experts and so on, may be useful for assessing generic environmental impacts or estimating that of processes that can realistically be represented by proxies. Similarly, such entities would also have valuable insight into the development of environmental regulations, and should thus be more accurately able to foresee regulatory shocks.

Finally, research and academic institutions would be integral to these studies, as they would have unique detailed specific knowledge on the required domains for assessment.

Expected Impacts

As an outcome of this exercise, POLSA would have an improved ability to judge the environmental impact of their space industry, which is the first step toward identifying hotspots and areas for improvement. In combination with the objectives defined in the previous action, industry can be made aware of these areas and develop solutions for improvement. Aside from the reduction of environmental impacts, this would bring innovation to the Polish space industry and could bring access to additional funding from environmentally interested initiatives such as the EU Green Deal.

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[55] ECHA. Candidate List of substances of very high concern for Authorisation. [online] available: https://echa.europa.eu/candidate-list-table/-/dislist/details/0b0236e1807da31d [accessed: 11/12/20]

Additionally, this improved understanding of the environmental impacts would lead to more robust risk assessments for the sustainable use of space. If the industry can identify areas for improvement and address these, this would be a hedge against negative public perception (regarding increased public interest in sustainability) and against regulatory or supply shocks from environmental regulations (tightened regulations at an EU level or in supplier states could impact space activity in Poland).

Finally, with increased EU and EU member state level interest in environmental and space sustainability. Poland's demonstrable commitment to this subject would align it with the objectives of the rest of the European community.

Key success factors

To achieve this, POLSA would need to commit capital to these studies, and be capable of allocating the capital to the most promising and impactful initiatives. It might be prudent to set up an expert board consisting of space and sustainability stakeholders to accurately judge the most promising projects.

As with the previous action, supporting a diverse range of projects would hedge against risk of investing in less rewarding areas, or potentially missing an area for which the environmental and regulatory risks are significant or for which improvements could easily be made.

Figure 30: Summary of Action 4.2

Required capabilities

- Allocation of sufficient funding
- Sufficient knowledge of the industry to judge most promising areas of study

Expected Impacts

- Improved assessment of current sustainability of the space sector
- Robust environmental and regulatory risk assessment of the sector
- Alignment with EU and MS commitments

Stakeholders involved

- Environmental analysts / experts
- Space system manufactures
- Academic institutions

Key Success Factors

- Proper identification of promising areas of study
- Selection of diverse areas for study

5.4.1 Action 4.3 – Set up workshops and conventions of the Polish space industry to spread awareness of space sustainability

PwC would recommend that POLSA takes a stewardship role by facilitating the dissemination of ideas, best practices and knowledge of space sustainability, as well as by raising general awareness of this emerging issue. The concrete action that POLSA can take is to set up or host workshops and conventions bringing together the industry, public authorities and academic institutions.

As space sustainability is a field in its infancy, knowledge and awareness is somewhat scare relative to that of other space fields. Such gatherings would serve to give this issue a platform where the Polish space ecosystem (and beyond) can further consider this issue. Beyond just raising awareness, this could serve as networking events and the nucleation points for further dialogue and development on space sustainability.

Required Capabilities

Such events would require a bringing together of the industry in a location where ideas can be shared and discussion can be fostered. The POLSA would need to attract entities from both within and beyond Poland to maximise the benefit from these events.

This action would need be undertaken starting after the preceding two actions, as the added value would be greater when POLSA has some knowledge of the state of play of space sustainability in the nation, and when some initiatives are already being undertaken.

Stakeholder involved

Successful awareness raising would entail reaching the broadest audience as efficiently as possible. This would typically involve Polish industry and public entities, but also involve entities such as ESA Clean Space who are well experienced in the subject and foreign industry as well to encourage cross fertilization of ideas.

Expected Impacts

If successful, the attendees of these events should have an increased awareness and appreciation of space sustainability issues. In addition to this, the networking effect of this event would ideally lead to new ideas being injected into the Polish space industry, best practices being shared and potential new partnerships forming between Polish actors and others, which would foster further innovation on space sustainability.

Finally, this would also present Poland as a leader in this emerging field, which would lead to positive reputational impacts for the Polish space industry and increased soft power for the Polish Space Agency.

Key success factors

The key success factors would be attracting enough of the industry such that awareness, information and best practices are shared wide enough, and that engaging and innovative discussion can be fostered.

This would require that there is already some interest in space sustainability in Poland, meaning that this action should be taken shortly after the preceding two to ensure that the topic has enough momentum to carry on during the workshops/conventions.

Figure 31: Summary of Action 4.3

Required capabilities	Expected Impacts
• Industry knowledge, awareness and interest in space sustainability	• Improved awareness and appreciation of space sustainability in industry • Sharing of ideas, knowledge and best practices • Improved networking and development of industrial relationships

Stakeholders involved	Key Success Factors
• Policymakers • Polish Space Industry • Foreign Space Industry • Academic Institutions	• Sufficient interest in the subject across industry

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Contact

Luigi Scatteia
Partner, PwC Space Practice Leader
Mobile: +33 (0) 6 42 00 71 67
scatteia.luigi@pwc.com

Agnieszka Gajewska
Partner, PwC Advisory Poland
Agnieszka.gajewska@pl.pwc.com